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ERGONOMICS EVALUATION OF LAW ENFORCEMENT CHEMICAL/BIOLOGICAL (CB) PERSONAL PROTECTIVE EQUIPMENT FOR THE LAW ENFORCEMENT ADVANCED PROTECTION (LEAP) CB STANDARDS ASSESSMENT

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November 2007 – March 2008

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Natick, Massachusetts 01760-5019

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14. ABSTRACT
The evaluation described in this report tested chemical/biological (CB) ensembles to determine the impact on ergonomic and human factors performance. The performance of each CB ensemble was compared to the performance of the baseline duty uniform. Statistically significant differences were found in many areas, indicating that wearing the CB ensemble adversely affects the ergonomic performance when compared to the baseline duty uniform. CB ensembles were evaluated using two separate human test subject groups, including military personnel and state police troopers. While wearing each ensemble, the two test groups performed a series of tasks, including timed donning and doffing, gross and fine hand dexterity tasks, body mobility tasks, and law enforcement based mission scenarios. Each test subject also performed these tasks wearing only the duty uniform, which served as the baseline level of performance. The recommendations identified within this report will be provided to the National Institute of Standards and Technology – Office of Law Enforcement Standards (NIST-OLES) for consideration when developing law enforcement specific CB standards.

15. SUBJECT TERMS

POLICE	SCENARIOS	COORDINATION	TASK PERFORMANCE
MOBILITY	BASE LINES	HUMAN FACTORS	TEST AND EVALUATION
UNIFORMS	STANDARDS	DATA COLLECTION	PROTECTIVE CLOTHING
ENSEMBLE	ERGONOMICS	LAW ENFORCEMENT	PERFORMANCE CRITERIA
DEXTERITY	CB PROTECTION	MANUAL DEXTERITY	
HUMAN FACTORS ENGINEERING		PPE(PERSONAL PROTECTIVE EQUIPMENT)	

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Preface

This report documents an ergonomics evaluation that tested multiple chemical/biological (CB) ensembles to determine the impact of their use on performing hand dexterity functions, range of motion tasks, and mission based scenarios. The performance of each CB ensemble was compared to the performance of the baseline duty uniform. The evaluation was accomplished by testing three CB ensembles using two separate human test subject groups, including military personnel and state police troopers. While wearing each ensemble, the two test groups performed a series of tasks.

The recommendations identified in this report will be provided to the National Institute of Standards and Technology – Office of Law Enforcement Standards (NIST-OLES) for consideration when developing law enforcement specific CB standards.

The evaluation was performed by the U.S. Army Natick Soldier Research, Development and Engineering Center's (NSRDEC) National Protection Center (NPC), during the period November 2007 to March 2008 under InterAgency Agreement # M42356 with NIST-OLES. The project was funded by the Department of Homeland Security (DHS), Science and Technology Directorate (S&T), Test and Evaluation and Standards Division (T&E/Stds).

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ERGONOMICS EVALUATION OF LAW ENFORCEMENT CHEMICAL/BIOLOGICAL (CB) PERSONAL PROTECTIVE EQUIPMENT FOR THE LAW ENFORCEMENT ADVANCED PROTECTION (LEAP) CB STANDARDS ASSESSMENT

1 Introduction

The Law Enforcement Advanced Protection (LEAP) Program spearheads a national effort to address multi-hazard protection using an integrated systems approach. This report describes an evaluation that directly supports the chemical/biological (CB) Standards Assessment Project, a subcomponent of the LEAP Program, which is focused on analyzing standards, requirements, and performance considerations in the context of law enforcement (LE) CB response during Homeland Security Operations (HLSO).

LE CB response has unique operational requirements which are not specifically addressed in current CB personal protective equipment (PPE) standards. These include varying degrees of mobility and dexterity required to complete LE mission related tasks. A minimum level of performance within these areas is required while maintaining the necessary levels of CB protection.

This evaluation was performed by the U.S. Army Natick Soldier Research, Development and Engineering Center's (NSRDEC) National Protection Center (NPC) between November 2007 and March 2008. It was commissioned by the Department of Homeland Security (DHS) Science and Technology Directorate (S&T), Test and Evaluation and Standards Division (T&E/Stds), through the National Institute of Standards and Technology – Office of Law Enforcement Standards (NIST/OLES). This evaluation was designed to examine the LE's unique ergonomic and human factors issues by assessing specific performance areas, including range of motion, dexterity, and mission related task scenarios.

The deficiencies identified in this report directly support the CB Standard Assessment Project's objective to assess performance considerations for LE CB response. The results of this evaluation will aid in identifying system level ergonomic requirements for LE CB ensembles.

2 Approach

The evaluation used a dual approach, involving laboratory and mission scenario testing, to quantify the performance of CB ensembles. The testing incorporated aspects of standardized test methods and knowledge from prior ergonomics evaluations[1] to properly customize the test protocol. This chapter provides critical details regarding the experimental design used to evaluate the CB ensemble performance, including test subject description, CB ensemble configurations, laboratory test procedures, and mission scenario test procedures. These test method details are described in Sections 2.4.1 and 2.4.2.

Laboratory tests included donning, doffing, gross dexterity, fine dexterity, and gross body mobility. Three mission scenarios that LE personnel may need to complete while wearing a CB system were replicated: perimeter control, tactical operations, and crime scene investigation.

2.1 Test Subjects

Two groups of four individuals participated in the evaluation. The first group of four consisted of enlisted Soldiers from the NSRDEC's Human Research Volunteer (HRV) Program. The HRV group had neither prior formal training nor experience using the CB PPE ensembles and respirators of the types evaluated. This "inexperienced" group was included in this evaluation along with an "experienced" group for the following reasons:

- Certification organizations will potentially use individuals who are inexperienced with CB PPE systems for testing and certification.
- Subjects inexperienced in the use of these CB PPE ensembles can help to detect possible inadvertent bias, either for or against a particular ensemble tested by experienced users.
- Although "better" data may be generated from an "experienced" user group, data needed for the standard must incorporate a broad range of user experience.

The second group of test subjects was from the Massachusetts State Police (MSP) Special Tactical Operations (STOP) Team. These subjects are "experienced" in that they are familiar with the type of equipment used in conjunction with the CB ensembles and the type of tasks associated with LE CB mission roles. The MSP STOP Team members also have extensive training and familiarity with CB PPE ensembles and respirators.

For data reporting purposes herein, the two groups are referred to as the HRV group and the Trooper group, respectively. Each group performed the tests separately. The data were collected and analyzed for each group allowing for comparison between test groups. The overall data set will be used to recommend system-based performance levels.

2.2 CB Suits

Three different CB protective suits were used for this evaluation. The design, construction, and materials of each suit were different. These suit design differences are important because they

[1] Hennessy, E. R. and Zielinski, M. R. Results of Benchmarking Ergonomics Evaluation of Explosive Ordnance Disposal (EOD) Suits for EOD PPE Standard Program. Final Report—NATICK/TR-06/014. US Army Research, Development, and Engineering Command, Natick Soldier Center. June 2006

can uniquely impact human factors performance. Each suit is described briefly in the following three subsections.

2.2.1 Suit A - Impermeable

Suit A (shown in Figure 1) was an impermeable, one-piece coverall with attached hood and booties. It was comprised of a barrier membrane laminated to an inner surface of a polypropylene substrate. The suit has a front zipper closure protected by an adhesive material flap. There are elastic closures at the wrists and mask interfaces. Suit A's integral booties were incompatible with the subjects' combat boots, and were therefore removed from the suit prior to testing. It is possible that their removal may have affected the ensemble's performance or test subjects' perceptions in certain areas. The configuration, without booties, remained consistent throughout the testing to reduce variability.

Figure 1. Impermeable CB PPE (Suit A)

2.2.2 Suit B - Selectively Permeable Membrane (SPM)

Suit B (shown in Figure 2) was a one-piece suit made from a selectively permeable membrane (SPM) material with a detached impermeable hood. The suit has a front zipper closure, protected by an SPM flap secured with hook and loop. The wrist and ankle closures are similar in design to an inner and outer closure. This closure system provides a layered seal (e.g., inner glove, inner sleeve closure, outer glove, and outer sleeve closure) that creates a tortuous path to restrict possible intrusion of CB agents. The detached hood also is a two layer system with an inner and outer skirt. The inner skirt is secured inside the CB suit while the outer skirt remains outside the suit. This system is a variant of the All Purpose - Personal Protective Ensemble suit, currently used by the U.S. Special Forces.

Figure 2: SPM CB PPE (Suit B)

2.2.3 Suit C - Air Permeable

Suit C (shown in Figure 3) was a two-piece system made from an air permeable, carbon-based protective technology. The suit includes both a coat and trousers. The coat has an attached hood, which is secured around the mask using a pull string system. The front zipper closure is protected by a carbon-based material flap secured with hook and loop. The coat has sizing adjustments at the waist. Wrist closures are also tightened using a hook and loop closure. The trousers are designed similar to bib overalls with sizing adjustments on each shoulder strap. They also have a pull string closure at the ankles. Though its design is similar to the military's Joint Service Lightweight Integrated Suit Technology (JSLIST) garment, it is lighter in weight.

Figure 3. Air Permeable CB PPE (Suit C)

2.3 Other CB Equipment

The evaluation assessed the performance of the entire CB protective system. Therefore each system also included respiratory protection, gloves, and overboots. These items are described in the following subsections.

2.3.1 CB Respiratory Protection

A 3M™ FR-M40 air purifying respirator (APR) mask, which is similar to the military M40 mask, was used for all of the evaluation tasks. A Scott® self-contained breathing apparatus (SCBA) was also used. However, due to limitations in the human use protocol and refilling requirements for the air supply tanks, the SCBA was only used for the timed donning and doffing procedures. Both respirator types are approved by the National Institute for Occupational Safety and Health (NIOSH) and are commercially available.

2.3.2 Gloves

Two different glove systems were used during the evaluation. Selection was based on the CB garment manufacturers' recommendations for CB ensemble component configuration. Standard 14 mil[2] butyl rubber gloves were worn with Suits A and C. Suit B used a two-piece glove system consisting of chemical protective liners worn under a Canadian flyer's over-glove. All glove types are commercially available.

[2] "mil" refers to thickness of the glove material (1 mil = 0.001 in).

2.3.3 Overboots

Two different types of overboots were used during the evaluation. Selection was based on the CB garment manufacturers' recommendations for CB ensemble component configuration. Standard butyl overboots were worn with Suits A and C. This overboot was secured using a series of three butyl rubber closures located on the front of the boot. A lighter weight, impermeable membrane overboot was worn with Suit B. This overboot was secured using a pull string closure at the top of the boot and two additional hook and loop closures, one at the ankle and the other at the heel. Both types of overboots are commercially available.

2.3.4 Test Ensemble Summary

The test ensembles for the evaluation were configured as follows:

- ***Ensemble A*** **-** consisted of Suit A, APR, standard butyl gloves, and butyl overboots. (Suit A's integral booties were removed prior to the evaluation.)
- ***Ensemble B*** **-** consisted of Suit B, APR, two-piece glove system, and lightweight impermeable overboots.
- ***Ensemble C*** **-** consisted of Suit C, APR, standard butyl gloves, and butyl overboots.
- ***The Duty Uniform*** **-** was the baseline condition for testing. The HRV group wore their Army Combat Uniforms (ACUs). The Trooper group wore a Battle Dress Uniform (BDU) and combat boots. The duty uniform trousers and boots were worn under each CB suit ensemble.[3]

2.4 Test Procedure

Although the evaluations of the HRV and Trooper groups were conducted separately, each group performed the same activities in the same locations. Prior to testing, demographic information was collected[4], and the subjects were fitted for all suits, boots, gloves, and respirators. Sizing information was recorded. Test subjects familiarized themselves with the equipment before the evaluation took place by donning and doffing all of the equipment in the proper size.

The subjects then began the two-part procedure, which consisted of laboratory-based tasks and the three mission-based scenarios. Subjects performed all tests in each of the three ensemble configurations and in their duty uniform alone. The order of configurations worn in a particular trial was randomly assigned prior to the start of testing. Each uniform/ensemble configuration was presented first, second, third, or fourth an equal number of times to the two groups. This was done to minimize, as much as possible, any fatigue or practice effects that could occur.

[3] Some performance differences may have been due to the different design, materials, and fit of the ACU compared to the BDU. However, all performance changes for a subject in a particular ensemble are expressed as a percentage relative to that subject. In other words, the overall benefit or disadvantage of wearing the duty uniform by itself is still captured for all three CB ensembles.

[4] This included: age, experience, time in unit, military occupational specialty (MOS) for military subjects, and CB equipment experience.

2.4.1 Part I—Laboratory Testing

The subjects completed the tasks described in the following subsections for each test ensemble configuration.

2.4.1.1. Donning and Doffing

The subjects began trials wearing their duty uniforms, and the time to don all components within the test ensemble was recorded. Any components requiring removal and re-donning in the course of donning an ensemble were also identified (e.g., non-attached hoods and gloves). Once they completed those trials, the subjects doffed the entire ensemble, and the time was recorded. Each test was conducted twice, first using the SCBA and then using the APR. All donning and doffing was unassisted, and the test subjects were asked to subjectively rate the ease or difficulty of these tasks for each ensemble. Test metrics included time to complete donning and doffing and the ease or difficulty of these tasks.

2.4.1.2 Gross Dexterity (Hand Manipulation)

The Minnesota Manual Dexterity Test is a standardized test used in many occupational and vocational environments for measuring gross finger and whole-hand dexterity. For this evaluation, the test was modified to use 28 of the 60 total[5] disks. During this test, the subjects picked up and turned over a series of wooden disks with their dominant hand and replaced the disks on the other end of the board with their non-dominant hand. The board was placed on a table, while the test subject sat near the board to comfortably manipulate the disks.

The subjects performed this dexterity test twice in each test ensemble, with a short break between the first and second trials. Prior to testing, the subject had a 10-minute practice session in the duty uniform alone. This reduced any improvement in time to complete the task due simply to a practice effect. Each subject's final time for comparison was the arithmetic mean of the two timed trials.

2.4.1.3 Fine Dexterity

The O'Connor Fine Finger Dexterity Test is a standardized test for measuring fine finger dexterity. Each subject picked up and placed 3 pins in each of 20 holes in a pegboard, using only the preferred (dominant) hand.

The subjects performed this dexterity test twice in each test ensemble, with a short break between the first and second trials. Prior to testing, each subject had a practice session in the duty uniform alone. This reduced any improvement in time to complete the task due simply to a practice effect. Each subject's final time for comparison was the arithmetic mean of the two timed trials.

2.4.1.4 Gross Body Mobility

Most of the gross body mobility data were generated using a goniometer, which quantifies range of motion by measuring the angular displacement of a body joint, such as an elbow, shoulder, or

[5] The board has 15 rows of 4 disks; the modified version uses 7 rows.

knee. (Full details on executing these tests are presented in other references.[6] The tasks require knowledge of the anthropometry[7] of the human body for proper execution.)

Prior to the start of the walking tests, a measurement tape was affixed to the floor to record the distance traveled. For each task, the subjects were asked to stretch and were instructed about the movement they had to perform. They then performed the movement. Subsequently, their movement displacements, angular or linear when appropriate, were recorded. The following gross mobility tasks were performed:

- **Walk Forward Five Steps:** The subject takes five steps forward, each step as far forward as possible. The distance traveled is measured and recorded from the heel of the foot when starting to the heel of the foot taking the fifth step.

- **Walk Backward Five Steps:** The subject takes five steps backward, each step as far backward as possible. The distance traveled is measured and recorded from the toe of the foot when starting to the toe of the foot taking the fifth step.

- **Side Step Five Steps:** The subject takes five steps sideways, each step as far sideways as possible. The distance traveled is measured from the outside of the foot when starting to the outside of the foot completing the fifth step.

- **Upper Arm Abduction:** The subject raises an arm sideways and upward as far as possible. A goniometer measures the angle of abduction.

- **Upper Arm Forward Extension:** The subject raises an arm as far forward and upward as possible. A goniometer measures the angle of forward extension.

- **Upper Arm Backward Extension:** The subject raises an arm as far backward and upward as possible, with the palm facing away from the body. The subject stands at a corner to prevent bending at the waist, which will artificially increase the angle. The goniometer measures the angle of backward extension.

- **Upper Leg Forward Extension:** The subject raises a leg as far forward and upward as possible while holding the back of a chair for support. A goniometer measures the angle of forward extension.

- **Upper Leg Backward Extension:** The subject moves a leg as far backward and upward as possible while standing against a wall for support. The goniometer measures the angle of backward extension.

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[6] Johnson, R.F., Effects of explosive ordnance disposal (EOD) armor on the gross body mobility, psychomotor performance, speech intelligibility, and visual field of men and women. Final. Report – NATICK/TR-81/031. U.S. Army Natick Soldier Research, Development and Engineering Center. 1981.

[7] Anthropometry is the study of human body measurements to assist in understanding human physical variations. http://ergonomics.about.com/od/glossary/g/anthropometry.htm [cited Sept. 2008.]

- **Upper Leg Flexion:** The subject raises an upper leg as far upward as possible, allowing the knee to bend freely while grasping a support (the back of a chair) and raising the leg. The goniometer measures the angle of flexion.

- **Standing Trunk Flexion:** The subjects attempt to touch the floor at a point just in front of their feet while standing with their feet a shoulder width apart. The subjects keep their knees locked and bend only their trunk. The distance between the fingertips and the floor is measured in centimeters.

- **Kneel and Rise:** The subjects are rated on their ability to rise from a kneeling position, either with or without assistance. They begin in a standing position, get down on both knees, and stand up again. The rating scale is: 0 = cannot get down on both knees, 1 = cannot rise from kneeling position without help from an experimenter, 2 = can rise from kneeling position but needs to grasp an object, and 3 = can rise from kneeling position without any help at all.

Each mobility task except kneel and rise was conducted three times in immediate succession for each test ensemble. The test score is the arithmetic mean of the three trials. Kneel and rise is a pass/fail task, and was run only once for each ensemble.

2.4.2 Part II—Mission Scenarios

Three different mission scenarios were developed that simulated distinct CB response mission roles: perimeter control, tactical operations, and crime scene investigation. These roles are discussed in the LEAP Program's "CB Gaps Analysis" report.[8] The mission scenarios were based on analyses of user focus groups,[9,10,11] existing consensus and military performance standards, ASTM and InterAgency Board (IAB) documentation, intelligence information, health hazard assessments, subject matter expert interviews, and relevant literature that outlines deficiencies in PPE for the LE community. During actual operations, some of the mission role tasks are usually conducted by teams. For example, tasks in the tactical scenario are often conducted by two to four officers. However, for this evaluation, every task was designed to be performed by a single subject. This was to ensure that issues arising for test subjects were accurately noted and tasks were timed properly. It also simplified data collection. However, in all cases, the tasks performed were typical of those required during the scenario's mission.

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[8] Castellani, S.; Kanagaki, G.; and Rodriguez, A. *Gaps Analysis of Chemical/Biological Protective Ensembles for the Law Enforcement Advanced Protection (LEAP) Program* – Final Report – NATICK/TR-09/024L U.S. Army Natick Soldier Research, Development and Engineering Center, National Protection Center (NPC), for Department of Homeland Security Office of Science and Technology Standards and National Institute of Standards and Technology/Office of Law Enforcement Standards. September 2009.

[9] DiChiara, A. ; Addonizio, M. *Law Enforcement Advanced Protection (LEAP) Requirements Focus Group Report.* Final Report – NATICK/TR-07/021. September 2007.

[10] "Requirements Assessment – Personal Protective Equipment (PPE) for Law Enforcement in Chemical, Biological, Radiological and Nuclear (CBRN) Environments." CTC Inc. September 2006.

[11] Creighton T.E. II. Bradley Hibbard, B.; Doherty, S.; and McManus, K. *Massachusetts State Police Special Tactical Operations Team User Focus Group – Law Enforcement Advanced Protection (LEAP) Duty Uniforms, Integrated Head Protection, Chemical/Biological Protection and Human Systems Integration*, CTC, Inc., May 2008.

The perimeter control and crime scene investigation scenarios were timed based on completion of all tasks without further subdivision. The scenario for tactical operations was decomposed into eight discrete subtasks. Each subtask was timed individually, and a total time was generated for each scenario. Test metrics were the time to complete the entire scenario and/or task as applicable. In addition, evaluators recorded any problems or difficulties completing tasks. After finishing each scenario, the test subjects completed a brief questionnaire regarding their experiences.

The four ensemble configurations previously identified were used to assess performance in each of the three mission scenarios. Each scenario also used a variety of mission-specific items worn or carried by the test subjects. These items differed by scenario and were representative of equipment commonly used by LE personnel, e.g., weapons, handcuffs, ASP, gas mask, etc.

Before the actual timed trial, subjects were familiarized with the scenario and performed a dry run. This ensured that all questions could be answered prior to the actual testing, and it reduced the likelihood that the learning process would affect the end results. Although the subjects were verbally coached[12] during the scenarios if necessary, they were not assisted in any other way during the trial.

2.4.2.1 Perimeter Control Scenario

This scenario was based on tasks an officer may be required to complete while performing perimeter control duties. The perimeter control officer is responsible for reducing overall "impact and consequences of an incident or major event by securing the affected area, including crime/incident scene preservation issues as appropriate, safely diverting the public from hazards, providing security support to other response operations and properties, and sustaining operations from response through recovery."[13] Perimeter control officers are typically charged with containing the situation at the cold/warm and warm/hot zone lines to ensure that the incident scene is secured and access is controlled. In addition, the perimeter control officer provides security support for other response operations. This officer also disseminates emergency information to the public, mitigates any further risks to the public, and addresses any issues concerning preservation of the crime/incident scene.[14] A scenario was developed which captured the primary tasks required during perimeter control operations.

Each subject wore the test ensemble with concealable body armor under the BDU/ACU coat. The subject also wore a duty belt with a 9 mm mock weapon and holster, a radio (without speaker/microphone), a flashlight, and a magazine pouch. If the test ensemble had pockets, the subject stowed a pen and a folded piece of paper (8 ½ x 11 in) in the pocket of the subject's choice. A roll of caution tape and a first aid kit were also stored at the staging area, which was the scenario start/end point. These items were placed on the ground adjacent to the start mark.

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[12] A verbal reminder, if necessary, was issued quickly at a point where elapsed time for the task was not affected. If for any reason the elapsed time was affected, the time was discarded and the task was re-run.

[13] "Target Capabilities List, A Companion to the National Preparedness Goal," U.S. Department of Homeland Security" (August 2006): page 321.

[14] Ibid. page 321.

After donning the test ensemble and mission specific equipment, the subject proceeded to the starting point. This scenario, depicted in Figure 4, was conducted outdoors using three large trees as anchor points for the caution tape.

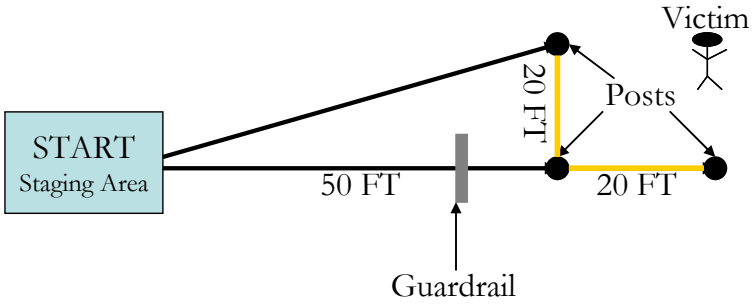

Figure 4: Graphical Representation of the Perimeter Control Scenario

The three trees used in this scenario were in an "L" configuration. The first and second trees were 20 ft apart in a line parallel to the blacktop, which stretched from the staging area to the farthest post, 70 ft away. The third tree was 20 ft from the second tree and formed a line perpendicular to the blacktop. The test site could be modified by the testing organization to accommodate the area available; however, all tasks must be included. In addition, approximately the same layout and total distances should be used for all baseline and performance testing. The intent of this ergonomics testing is to have consistent data between suit condition tests to measure performance changes.

This scenario consisted of the following tasks and instructions:

- Receive "start" signal.
- Pick up the caution tape on the ground at the staging area.
- From the staging area, run 70 ft down the blacktop to the first tree to be secured.
- Secure the caution tape around the first tree, and roll out at least 25 ft of tape to secure the other end around the second tree, with the tape approximately 4 ft off the ground. Rip off the end of tape, and hold onto the tape roll.
- Note a "shift in wind," and run back 50 ft to the staging area.
- Run to the third tree, and mark off another perimeter. Use at least 20 ft of caution tape to connect the second and third trees. Rip off the end of the tape, and hold onto the tape roll.
- Return to the starting point. Drop the tape roll. Retrieve the radio from your belt. Use the radio to call the command center, stating that the perimeter is secure. Re-stow the radio.
- Retrieve the paper and pen from your pocket. Draw a rough sketch/map of the scene.
- Re-stow the pen and paper.
- Walk quickly back toward the second run of caution tape. In doing so, step over a (27-in-high) guardrail located 27.5 ft from starting point, turn around and crawl under the guardrail, and then head to the run of tape.
- Duck under the caution tape, and walk 5 ft beyond the tape to the "victim". Identify yourself to the victim standing in the secure area. Ask the victim if he is injured. The victim will respond that he has been shot in the upper arm. Escort him from the

cordoned-off area. (The "victim" is a member of the evaluation team, and not a test participant.)

- Once in the "safe area" (at the starting point), retrieve a bandage from the first aid kit. Wrap the victim's upper arm with the bandage.
- Stand up, and turn around toward the secured area.
- Draw the flashlight and weapon, turn the flashlight on, and pan the weapon and light across the area beyond the caution tape for 10 s. Stow the flashlight, and hold the weapon at your side.
- Run approximately 70 ft to the far end of the caution tape.
- Upon arrival in the area, re-deploy your weapon, aim, speak appropriate commands, and simulate firing two shots. Remove the magazine from the weapon, stow it, remove the new magazine from the belt, and insert the new magazine into your weapon. Re-holster the weapon.
- Go back to the staging area.
- The timer is stopped upon arrival at the staging area.

The total time required to complete the scenario and any difficulties completing the tasks were recorded.

2.4.2.2 Tactical Operations Scenario

This scenario was based on tasks an officer may be required to complete during a tactical operation. Tactical operations cover a wide range of tasks including typical special weapons and tactics (SWAT) operations necessary to neutralize situations, e.g., alleviating threats, apprehending suspects, searching, and seizing. Tactical operations also include evacuations, rescue operations, and threat mitigation activities. It may be necessary to remove affected victims and ensure that "affected and at-risk populations…are safely sheltered-in-place and/or evacuated to safe refuge areas."[15] A scenario was developed which captures the primary tasks required during tactical operations.

Each subject wore the randomized test ensemble with a tactical body armor/load carriage vest and the Advanced Combat Helmet (ACH). The vest is commercially available and is used by many police agencies for tactical operations. Standard handcuffs, a radio, and extra magazines were all mounted on the vest. A 9 mm handgun was mounted in a drop-down leg holster. The subject also carried a mock M4 rifle with a sling strap. An evaluation team member served as the "arrestee." A 120-lb dummy wearing a load-bearing vest with an extraction strap served as the "officer down."

After donning the relevant equipment, the subject proceeded to the starting point. The subject began by holding the M4 at the ready position with the handgun holstered.

This scenario, depicted in Figure 5, was conducted indoors, in and around the NSRDEC Center for Biomechanics Research laboratory.

[15] Ibid: page 434.

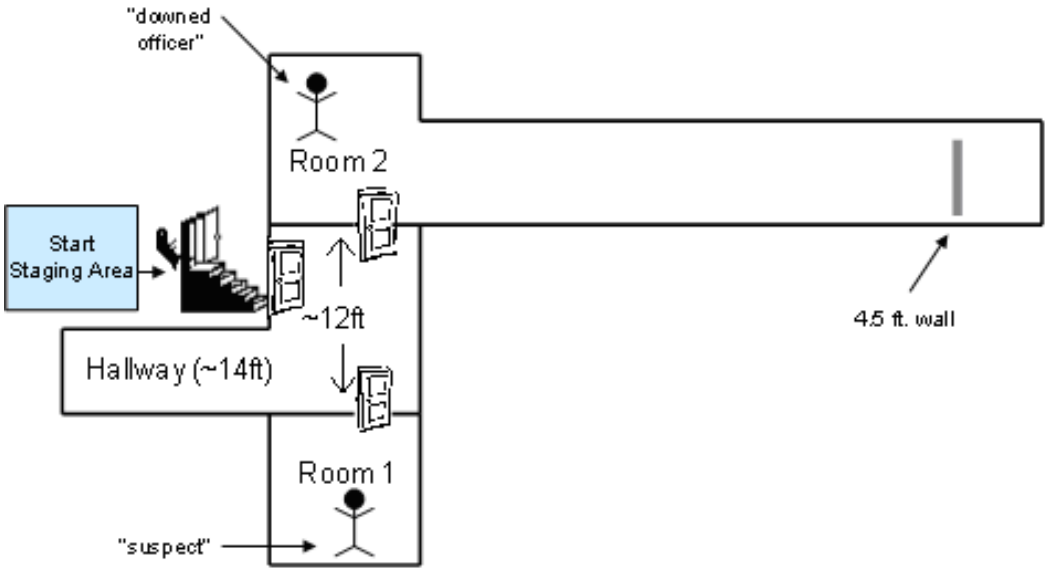

Figure 5: Graphical Representation of the Tactical Scenario

The test site included a stairwell, adjacent hallway, two separate rooms, an approximately 60 ft open area, and a 4.5-ft-tall wall. The test site could be modified by the testing organization to accommodate the area available; however, all tasks must be included. In addition, approximately the same layout and total distances should be used for all baseline and performance testing. The intent of this ergonomics testing is to have consistent data between tests to measure performance changes.

This scenario consisted of the following tasks and instructions and time points noted:

- Climb 13 stairs to the landing/staging area; await the "go" signal.
- On the "go" signal, descend 13 stairs to the bottom of the staircase. Turn right; proceed 9 ft back from the foot of the stairs to inspect/clear the area under the stairs. Return to the foot of the stairs.
- Exit the stairwell door, turn right, and walk 12 ft down the hallway. Turn right into a perpendicular hallway, walk 14 ft up the hallway, and clear the hallway. Return to the first hallway.
- Turn right, and walk 4 ft to the doors. Pass through the doors. Find the armed suspect, 12 ft beyond the doorway.
- Order the suspect to drop his weapon, and go prone (suspect obeys and does not resist). (Time 1)
- Drop the shoulder weapon (caught by sling), and draw the sidearm. Change the magazine in the handgun. Train the sidearm on the suspect. (Time 2)
- Stand next to the suspect. Holster the weapon. Handcuff the suspect to restrain his arms behind his back. Ask appropriate questions of the suspect, who answers them. (Time 3)
- Frisk the suspect to ensure he is not armed. Stand the suspect up. (Time 4)
- Radio to the other team members outside that one suspect is in custody and that the team member will be exiting the door with that suspect. (Time 5)
- Escort the suspect out the door by grasping him by the arms or wrists.
- Simulate handing off the suspect to the team member in the hallway.

- Redeploy the shoulder weapon, and clear the hallway. (Time 6)
- Walk 16 ft, and enter the door straight ahead. Clear the area.
- Walk 7 ft into the room, and find a downed officer.
- Drag the downed officer 15 ft using the extraction strap on the officer's vest. (Time 7)
- Clear the shoulder weapon of malfunction.
- Run 64 ft to a 4.5-ft-high wall, and scale the wall.
- The Trooper is finished once his feet hit the ground on the opposite side of the wall. (Total time recorded and Time 8 calculated.)

2.4.2.3 Crime Scene Investigation Scenario

This scenario was based on tasks an officer may be required to complete during a crime scene investigation. Once the crime scene is secured, a crime scene investigation unit may be required to process the scene and conduct mortuary activities prior to hazardous material (HAZMAT) clean up. Crime scene investigation in a contaminated environment involves activities necessary to provide key forensic evidence for prosecutorial purposes, such as processing and removing evidence and any remains of deceased victims. A scenario was developed which captures the primary tasks required during crime scene investigations.

Each subject wore the randomized test ensemble and, prior to the evaluation, was assisted in donning 10-15 pairs of latex gloves (over the CB gloves if specified). Additional gear was carried by the subject, including a plastic toolbox (evidence collection kit) containing tweezers, index cards, a fingerprint brush, a roll of lifting tape, a ruler, several zipper plastic bags, a permanent marker, and a video camera. The subject also carried a digital still camera around his neck.

This scenario, depicted in Figure 6, was conducted indoors in the NSRDEC Center for Biomechanics Research laboratory.

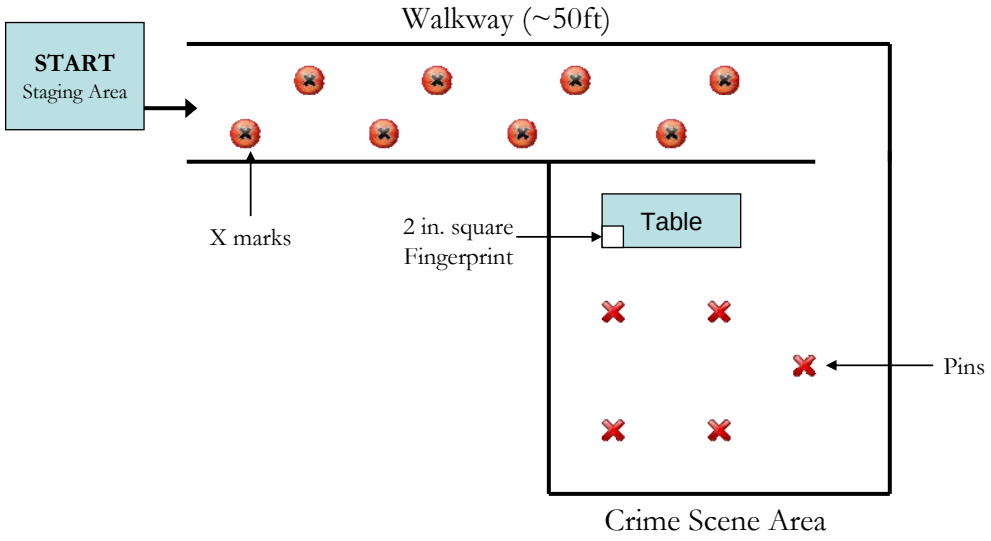

Figure 6. Graphical Representation of Crime Investigation Scenario

The test site included an open area of approximately 50 ft long, a table, and an open room. (The room was marked off for the staging area, walkway, crime scene area, and other features.) The test site could be modified by the testing organization to accommodate the area available;

however, all tasks must be included. In addition, approximately the same layout and total distances should be used for all baseline and performance testing. The intent of this ergonomics testing is to have consistent data between suit condition tests to measure performance changes.

This scenario consisted of the following tasks and instructions:

- Proceed to the starting point, where the evidence collection kit and camera are available, and await the "start" signal.
- Upon the "start" signal, pick up the still camera and toolbox. Walk 54 ft to the "crime scene". (The walkway is 3 ft, 3 in wide.)
- While walking down the path, a series of Xs are taped to the floor.[16] These Xs represent areas where you cannot step. Negotiate the path without stepping on any of the Xs and without stepping out of the path lines.
- At the end of the path, turn right, stop, open the kit, retrieve the video camera, and simulate videotaping the "crime scene". Stow the video camera, take a still photo of the scene, and proceed to a table 14 ft away.
- Photograph a "fingerprint" in a 2-in-square area marked off on the far side of the table.
- Retrieve the fingerprint brush, simulate dusting the print, tape the print, pull the tape, and place the taped print onto an index card. Photograph the carded print, and place the card in a plastic bag. Mark the bag with the date, and label it "Fingerprint 1".
- Remove the outer latex glove layer.
- Five small pins (from the O'Connor fine finger dexterity test) are on the floor in various locations around scene. Approach the nearest item, place a ruler near the item, and photograph the item.
- Mark a plastic bag with information as "Item 1". Pick up the item with a tweezers, and place the item in a bag. Secure the bag. Place the bag in the evidence kit.
- Remove the outer latex glove layer.
- Move on to the next nearest item, place a ruler near the item, and photograph the item. Bag, label, and store the item in the kit.
- Remove the outer latex glove layer.
- Move on to the next item, and continue collection, inventory, and glove removal until all remaining items (a total of five) are processed.
- Return to the starting point.

[16] The centers of all Xs were 2 ft apart front/back and side/side, and were 9" in from the sides of the path. The actual Xs were located at the following points in the path (L/R indicates to which side the X was located): 9'4" R, 11'4" L, 22'2" L, 24'2" R, 35'10" R, 37'10" L, 44' L, 46' R. See Figure 6.

3 Subject Demographics and Sizing

3.1 Demographics

Two groups of four males participated in this evaluation. The subjects in the first group were Soldiers from the NSRDEC's HRV Program who had neither prior formal training nor experience using the CB PPE ensembles and respirators of the types evaluated. The subjects in the second group were from the MSP STOP Team. The MSP STOP Team members have extensive training and familiarity with CB PPE ensembles and respirators.

Table 1 depicts basic demographic information collected from both groups.

Table 1. Test Subject Demographic Information

Subject Number	*Age*	*Time in Service/ State Police*	*MOS[a]/Job Title*	*Previous CB Experience*	*Dominant Hand*	*Glasses/ Contacts*
1	*20*	*7 months*	*19D Cavalry Scout*	*Basic training*	*Right*	*None*
2	*28*	*7 months*	*19D Cavalry Scout*	*Basic training*	*Right*	*None*
3	*20*	*9 months*	*19D Cavalry Scout*	*Basic training & NBC[b]*	*Right*	*None*
4	*30*	*9 months*	*19D Cavalry Scout*	*OSVT[c]*	*Right*	*None*
5	*38*	*7 years*	*State Police Trooper*	*CB training*	*Right*	*None*
6	*37*	*8 years*	*State Police Trooper*	*CB training*	*Right*	*None*
7	*39*	*10 years*	*State Police Trooper*	*CB training*	*Right*	*None*
8	*40*	*15 years*	*State Police Trooper*	*CB training*	*Right*	*Contacts*

[a] MOS = military occupational specialty
[b] NBC = nuclear, biological, and chemical
[c] OSVT= opposing forces surrogate vehicle training

Subjects 1 through 4 were from the HRV group. Subjects 5 through 8 were from the Trooper group. The subject numbers are the same in each table throughout this report unless otherwise specified.

The HRV group averaged 8 months in the military with a standard deviation (SD) of 1.15. Most subjects had only the nuclear, biological, and chemical (NBC) training provided to recruits in basic training. The subjects had a mean age of 24.5 years with an SD of 5.26 years. The HRVs were all cavalry scouts, MOS 19D,[17] though their main assignment while stationed at NSRDEC was to serve as test subjects for various research projects.

The Trooper group averaged 10.0 years of LE experience with an SD of 3.56 years. The Troopers were older than the HRVs with an average age of 38.5 years with an SD of 1.29 years. They receive regular training in CB through exercises, and all of them were familiar with CB PPE prior to the evaluation.

[17] http://www.army.com/resources/item/629 [cited September 2009]

3.2 Sizing

Although some bulk or slack was apparent in some cases with Suits B and C, neither was excessive. Bulk was less of a problem for Suit C, the two-piece suit, which allowed for fitting of different sizes of jackets and trousers. On the other hand, Suit A tended to be baggy on most of the subjects, though it fit properly based on the suit sizing scheme. In larger sizes, the Suit A was much longer (taller) than the subjects' height. If the subjects required a larger size to fit their girth, oftentimes a large amount of excess material had to be gathered in their upper torso area.

The fit of both types of overboots did not greatly affect donning and doffing, with one exception. One Trooper's duty boots had thick soles that wrapped around the boot heels. Although that Trooper used overboots that were sized properly, he often had difficulty donning and doffing the butyl overboots due to friction against the heel on his duty boots. However, his donning and doffing times were not increased due to the boots. This was confirmed through subjective statements from the test subject, observations of his donning and doffing trials, and a statistical check of his data.

All other test items fit the subjects without complications. Table 2 lists sizes of the various test items worn by the subjects.

Table 2. Test Item Sizes Worn by Subjects

Subject Number	Suit A Size	Suit B Size	Suit C Top Size	Suit C Bottom Size	Overboot Size	JB2GU Size	Butyl Glove Size	Helmet Size	Shoe/ Boot Size
1	M	L	L	M	L	M	M	L	10
2	L	XL	XL	L	XL	M	M	L	9
3	M	L	L	M	XL	M	M	L	11
4	L	XL	XL	L	L	L	M	L	10
5	L	XL	L	L	XL	M	M	M	10.5R
6	L	L	XL	L	XL	M	M	L	10.5W
7	L	L	L	M	XL	L	L	M	10R
8	L	L	L	M	XL	M	M	L	9.5W

Subjects 1-4 were HRVs; Subjects 5-8 were Troopers.

4 Ergonomics Evaluation Results

One objective was to determine the performance decrement caused by wearing CB ensembles when completing common LE CB response tasks. This was accomplished by comparing the results when wearing a test ensemble to results when wearing only the duty uniform.

There were six possible results for each test (e.g., donning, doffing, dexterity, range of motion, or mission scenario):

- A statistical difference exists in performance between test ensembles; that is, one ensemble performs statistically better or worse than another ensemble.
- No statistical difference exists in performance between test ensembles.
- A statistical difference exists in performance between a test ensemble and the duty uniform alone; that is, the ensemble performs statistically better or worse than the duty uniform alone.
- No statistical difference exists in performance between a test ensemble and the duty uniform alone.
- An interaction effect exists between ensemble type and experience for the subject groups (for $p<0.05$).
- No interaction effect exists between ensemble type and experience for the groups (for $p>0.05$).

In order to determine the statistical significance of the data it was necessary to establish an acceptable level of confidence. The statistical relation, α, is set to a certain percentage. It is common to see this level set at $\alpha = 0.05$, and a p-value of $p = 0.05$, as was selected for this evaluation. When a normal data distribution is assumed, there is a 1 out of 20 (5%) probability of obtaining the statistical relation by chance. Throughout this evaluation, $p = 0.05$ was used as a guide. If $p<0.05$, there is a significant statistical difference between the groups. Significant interaction effects at $p<0.05$ for an evaluation task are circumstances where ensemble type and experience together affect the outcome, while neither one factor alone had an impact.

Multiple results from the bulleted list above can be observed for each group. For example, the following results could be observed for the upper arm abduction body mobility task:

- The Trooper group performed statistically different for Ensembles A and C and the duty uniform.
- Ensemble B was statistically worse than the duty uniform.
- There was no interaction effect between ensemble type and experience for the Trooper and HRV groups for this specific task.

Therefore, each test must be analyzed for each of the six possible outcomes when assessing the efficacy of ensemble performance for LE CB operations.

Statistical Analysis Approach:
Depending on the data sets, two different statistical analyses were conducted. Student's paired t-tests[18] were used to analyze most results. The paired t-test is used when there is one measurement value and two nominal values. In this case, performance (measurement value) was measured with a test ensemble (nominal value 1) and with the baseline duty uniform (nominal value 2).

Each of the three ensembles was analyzed against its baseline duty uniform performance. This was completed for all tests except donning and doffing. Those trials were not compared against a baseline condition and therefore could not be analyzed using the paired t-test. Instead, donning and doffing times were analyzed using repeated measures analysis of variance[19] (ANOVA). This method allows the test subject to essentially serve as his/her own control group and is used when the two sets of data measure the exact same characteristic.

The two test subject groups were analyzed separately to identify statistical differences between test ensembles within each group. Data from the two groups were also combined to assess interaction effects. The combined data were analyzed using repeated measures ANOVA, where the "ensemble type" was the "within-subjects variable" and "experience" was the "between-subjects variable". This analysis determined if the interaction between the two groups for each ensemble condition and experience level was statistically significant.

Presentation of Results:
The results of each test are presented in the following order:

- A short task description
- Results for each group (HRVs then Troopers)
  - Tabulated data comparing the mean and SD of the task for each ensemble
  - Key findings
  - Discussion of results
- A comparison of the two subject groups' results

4.1 Donning and Doffing

The subjects began trials wearing their duty uniforms. The time to don all components within the test ensemble was recorded. Any components requiring removal and re-donning in the course of donning an ensemble were also identified (e.g., non-attached hoods and gloves). Once the trial was completed, the subject doffed the entire ensemble, and the time was recorded. Each test was conducted twice, first using the SCBA and then using the APR. Mean completion times and SDs were calculated.

In addition, the subjects used a seven-point scale to rate the ease or difficulty of donning and doffing each ensemble with both types of respirators. The ratings were:

1 = Very Difficult
2 = Moderately Difficult

[18] Hays, William L. (1981). Statistics. Third Edition. New York: Holt Rinehart and Winston.

[19] Ibid.

3 = Slightly Difficult
4 = Neither Difficult nor Easy
5 = Slightly Easy
6 = Moderately Easy
7 = Very Easy

Repeated measures ANOVA were run for the timed data. The HRV group's results are reported in Section 4.1.1 followed by those for the Trooper group in Section 4.1.2.

4.1.1 HRV (Inexperienced) Group

4.1.1.1 Donning Time and Ease/Difficulty Results

Results Table(s):

Table 3 summarizes the mean completion times and associated SDs for donning with both the SCBA and APR. Donning time is reported in seconds (s).

Table 3. Mean Donning Times, HRV Group

	SCBA Donning Time		APR Donning Time	
	Mean (s)	**SD**	**Mean (s)**	**SD**
Ensemble A	447.8*	56.8	358.0*	49.8
Ensemble B	451.8	150.6	475.8	156.4
Ensemble C	288.5*	58.3	230.5*	47.2

*Ensemble times were statistically different at $p<0.05$.

Table 4 summarizes the mean ease ratings and corresponding SDs for donning with both the SCBA and APR. Ease of donning was rated by the subjects on the seven-point scale.

Table 4. Mean Ratings of Ease/Difficulty for Donning, HRV Group

	SCBA Donning Ease Rating		APR Donning Ease Rating	
	Mean	**SD**	**Mean**	**SD**
Ensemble A	3.5	1.7	2.8	1.0
Ensemble B	4.5	1.7	4.0	1.6
Ensemble C	5.3	2.2	6.0	0.8

Key Findings:

- **Timed Trials**
  - Ensemble C was statistically faster to don than Ensemble A for both the SCBA and APR trials.[20]
  - Ensemble B was the slowest to don and had the largest SD (roughly three times larger than the other ensembles) for both the SCBA and APR.[21]

[20] Performance improvements or decrements are not based on statistical observation unless indicated otherwise.

[21] A standard deviation (SD) as large as Ensemble B's for the mean donning time indicates that, although on average Ensemble B was the slowest to don, there was a large variation in the test results. This variation may be the reason why no statistical difference was found for Ensemble B.

- Ensembles A and C were statistically faster to don for the APR compared with the SCBA.

- **Ease Ratings**
  - Ensemble C was rated highest for ease of donning for both the APR and SCBA.
  - Ensemble A was rated lowest for ease of donning for both the APR and SCBA.

Discussion:

Regardless of the respirator used, Ensemble C was donned statistically faster than ensemble A. Ensemble C was a two-piece design, while ensemble A was a one-piece design constructed from a more rigid material. Ensemble A was also bulkier, which likely affected its donning time and ease rating. Ensemble B, also a one-piece, was between Ensembles A and C in donning times and ease ratings. Ensemble B was also more flexible and fit subjects better than Ensemble A.

Several subjects had to remove their duty boots to don Ensemble A, extending their times. Removal of their duty boots depended on the boot design, most often the heel and the legs/cuff tightness of Ensemble A. Ensemble A was the only ensemble with a mean ease rating below 4, indicating difficulty in donning.

4.1.1.2 Doffing Time and Ease/Difficulty Results

Results Tables:

Table 5 summarizes the mean completion times and associated SD for doffing with both the SCBA and APR. Donning time is reported in seconds (s).

Table 5. Mean Doffing Times, HRV Group

	SCBA Doffing Time		APR Doffing Time	
	Mean (s)	**SD**	**Mean (s)**	**SD**
Ensemble A	200.5 [a]	31.4	139.0 [b]	37.9
Ensemble B	130.3 [a]	18.7	135.8	44.2
Ensemble C	94.0 [a]	18.4	76.8 [b]	24.5

[a] Ensemble C was doffed statistically faster than ensembles A and B. Ensembles A and B were not statistically different at $p<0.05$

[b] Ensemble times were statistically different at $p<0.05$

Table 6 summarizes the mean ease ratings and corresponding SDs for doffing with both the SCBA and APR. Ease of donning was rated by the subjects on the seven-point scale.

Table 6. Mean Ratings of Ease/Difficulty for Doffing, HRV Group

	SCBA Doffing Ease Rating		APR Doffing Ease Rating	
	Mean	**SD**	**Mean**	**SD**
Ensemble A	4.3	1.3	4.3	2.1
Ensemble B	4.5	1.7	4.3	2.1
Ensemble C	6.5	0.6	6.7	0.6

Key Findings:

- **Timed Trials:**
  - Ensemble C was statistically faster to doff than Ensembles A and B for the SCBA.
  - Doffing times for Ensembles A and B were not statistically different for the SCBA.
  - Ensemble A was the slowest to doff and had the largest SD for the SCBA.
  - Ensemble C was statistically faster to doff than Ensemble A for the APR.
  - Ensemble A was the slowest to doff for the APR.
  - Ensemble B had the largest SD for the APR.

- **Ease Ratings, SCBA and APR**
  - Ensemble C was rated highest for ease of doffing for the SCBA and APR.
  - Ensemble A was rated lowest for ease of doffing for the SCBA and APR.

Discussion:

In general, the times tended to be quicker with the APR because the SCBA's harness was more complex. In addition, Ensemble C's design appears to have made ensemble doffing quicker and easier than either of the other designs. With the SCBA, Ensemble C's statistically quicker doffing time versus the other two ensembles is likely due, in part, to its design. Ensemble A's statistically slower time, versus that of Ensemble C with the SCBA and the APR, was likely due to the inability of Ensemble A's design to properly fit/size for multiple user heights and widths.[22] This statistically slower time could have also been affected by whether or not the subject was forced to remove his boots to doff Ensemble A. In general, slower mean times were rated with lower ease ratings.

4.1.2 Trooper (Experienced) Group

4.1.2.1 Donning Time and Ease/Difficulty Results

Results Tables:

Table 7 summarizes the mean completion times and associated SDs for donning with both the SCBA and APR. Donning time is reported in seconds (s).

[22] As described in Section 4.2, Ensemble A tended to be baggy on most of the subjects, though it fit properly based on the suit sizing scheme. In larger sizes, the suit was much longer (taller) than the subjects' height. If the subjects required a larger size to fit their girth, oftentimes a large amount of excess material had to be gathered in their upper torso area.

Table 7. Mean Donning Times, Trooper Group

	SCBA Donning Time		APR Donning Time	
	Mean (s)	**SD**	**Mean (s)**	**SD**
Ensemble A	341.3	59.8	280.8	30.3
Ensemble B	357.3	21.2	440.0	98.9
Ensemble C	307.0	30.9	243.3	42.8

Table 8 summarizes the mean ease ratings and corresponding SDs for donning with both the SCBA and APR. Ease of donning was rated by the subjects on the seven-point scale.

Table 8. Mean Ratings of Ease/Difficulty for Donning, Trooper Group

	SCBA Donning Ease Rating		APR Donning Ease Rating	
	Mean	**SD**	**Mean**	**SD**
Ensemble A	3.8	1.3	4.5	1.9
Ensemble B	4.3	1.5	3.3	1.5
Ensemble C	4.8	1.5	4.8	1.7

Key Findings:

- **Timed Trials**
  - None of the ensemble types was donned statistically faster than any other with either the SCBA or the APR.

- **Ease Ratings**
  - Ensemble C was rated highest for ease of donning for both the SCBA and APR.
  - Ensemble A was slightly easier to don than Ensemble B for the APR.
  - Ensemble B was slightly easier to don than Ensemble A for the SCBA.

Discussion:

A likely cause of the lack of statistical significance in donning the different ensembles is the large variance (the square of the SD) in donning times. Although there were no statistical differences in donning times in the Trooper group, ensemble design appears to have had some bearing on donning times and ease of donning for the Troopers. The Troopers had more difficulty donning Ensemble B's hood than the HRV group, as evidenced by observation, ratings, times, and participant feedback. This could have been attributed to the combination of the Ensemble B hood's design and fitting complexity, as well as the physiological size and/or shape of the Troopers' heads. Also, Ensemble C was the quickest and easiest to don. Ensemble A was quicker and easier to don than Ensemble B, although it was more bulky and rigid than either Ensemble B or C. As with the HRV group, some Troopers had to remove their boots to don Ensemble A. The Troopers rated the ease or difficulty of donning the three ensembles consistently with the times it took them to don each ensemble (i.e., slower donning times received lower ratings).

4.1.2.2 Doffing Time and Ease/Difficulty Results

Results Table(s):

Table 9 summarizes the mean completion times and associated SDs for doffing with both the SCBA and APR. Doffing time is reported in seconds (s).

Table 9. Mean Doffing Times, Trooper Group

	SCBA Doffing Time		APR Doffing Time	
	Mean (s)	SD	Mean (s)	SD
Ensemble A	139.3*	18.4	106.0	10.4
Ensemble B	140.5*	11.6	115.5	33.8
Ensemble C	92.5*	11.6	86.3	17.0

*Ensemble C was statistically faster than Ensembles A and B, and Ensembles A and B were not statistically different ($p<0.05$).

Table 10 summarizes the mean ease ratings and corresponding SDs for doffing with both the SCBA and APR. Ease of doffing was rated by the subjects on the seven-point scale.

Table 10. Mean Ratings of Ease/Difficulty for Doffing, Trooper Group

	SCBA Doffing Ease Rating		APR Doffing Ease Rating	
	Mean	SD	Mean	SD
Ensemble A	3.5	1.7	3.8	1.7
Ensemble B	4.8	1.3	5.5	1.3
Ensemble C	6.0	0.8	5.8	1.3

Key Findings:

- **Timed Trials**
  - Ensemble C was statistically faster to doff than Ensembles A and B with the SCBA.
  - Ensembles A's and B's doffing times were not statistically different with the SCBA.
  - None of the ensemble types was doffed statistically faster than any other with the APR.

- **Ease Ratings:**
  - Ensemble C was rated highest for ease of doffing with the SCBA and APR.
  - Ensemble A was rated lowest with the SCBA and APR.

Discussion:

In general, doffing times tended to be quicker with the APR because of the extra time required to unfasten the buckles and straps of the SCBA. In addition, Ensemble C's design appears to have made doffing quicker and easier than the other ensembles. Ensemble A's design may have slowed its performance.[23]

[23] Ensemble A tended to be baggy on most of the subjects, though it fit properly based on the suit sizing scheme. In larger sizes, the suit was much longer (taller) than the subjects' height. If the subjects required a larger size to fit their girth, oftentimes a large amount of excess material had to be gathered in their upper torso area.

The Troopers felt that doffing Ensemble B's hood was not as difficult as donning it. Despite the fact that Ensemble B was doffed more slowly than Ensemble A, the Troopers rated it easier to doff than Ensemble A. The Troopers often had to remove their boots to doff Ensemble A, making the process somewhat more difficult and lengthening the overall time. These issues were reflected in their ratings for Ensemble A for ease of doffing.

4.1.3 Combined Group Data Analysis—Donning and Doffing

HRV and Trooper groups' donning and doffing time data were combined to determine if these data were affected by the interaction between the ensemble type and experience level of the subjects. This analysis identifies whether a significant difference exists due to the combination of ensemble and experience variables rather than analyzing each variable independently.

Repeated measures ANOVA, which generalizes Student's t-test for paired samples, are used when two or more measurements of the same type are made on the same subject.[24] In this case, "ensemble" was the "main effect," and "experience level" was the "between subjects effect." Since the two groups of data are distinct data sets, only a test for any significant interaction effect was performed on the combined data.

Key Findings:

- There were statistically significant interaction effects ($p<0.05$) for donning and doffing times with the SCBA. Ensemble type and experience together affected donning and doffing times. Neither factor alone had an impact.
- None of the APR donning or doffing times had a significant interaction effect.

Discussion:

One possible explanation is that the Troopers' CB and special operations training may have influenced the Troopers donning and doffing times, resulting in a significant interaction effect.

4.2 Gross Dexterity

The Minnesota Two-Hand Turning Test is a good discriminator of gross dexterity differences. Two different glove systems were used as described in Section 2.3.2. Gross dexterity testing was conducted without gloves for the duty uniform condition. This test was intended to demonstrate the performance decrement caused by the addition of the CB ensemble. It was anticipated that wearing the CB suit and mask would have some impact on the results, though a smaller one than that caused by gloves. Therefore the dexterity testing was completed on the entire CB ensemble as it would be worn for response.

The data presented identify the statistical differences in ensemble performance when compared to the baseline duty uniform condition. All significance tests for each group were conducted as paired Student's t-tests.

[24] Gerard E. Dallal, Ph.D., "Repeated Measures Analysis Of Variance, Part I: Before SAS's Mixed Procedure." http://www.jerrydallal.com/LHSP/REPEAT.HTM [Cited September 2008]

4.2.1 HRV (Inexperienced) Group Results

Results Table:

Table 11 presents the HRV group's mean times and associated SDs for the Minnesota Two-Hand Turning Test by ensemble condition. Also presented are the performance decrements of the ensembles compared with the duty uniform condition.

Table 11. Minnesota Two-Hand Turning Test Results, HRV Group

	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	43.5*	4.4	32.8%
Ensemble B	54.1*	10.5	65.3%
Ensemble C	40.3*	7.0	22.9%
Duty Uniform	32.8	3.8	

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

Key Findings:

- All three ensemble conditions had statistically slower times to complete this task compared with the duty uniform.
- The percentage decrement values varied per ensemble condition:
  - Ensemble C performance decrement was 22.9%.
  - Ensemble A performance decrement was 32.8%.
  - Ensemble B performance decrement was 65.3%.

Discussion:

In the Minnesota Test, the subjects use their hands and fingers to manipulate the disks. Gloves that decrease the dexterity and tactility of the hands and fingers would likely affect test values. Ensemble B used a two-layer glove system, which contributed to the large performance decrement. This can be seen by comparing the performance decrements calculated for Ensembles A and C, which used the same glove system. In addition, the mask ensemble may have also negatively affected performance.

4.2.2 Trooper (Experienced) Group

Results Table:

Table 12 lists the Trooper group's mean times and associated SDs for completing the Minnesota Two-Hand Turning Test by ensemble condition. Also presented are performance decrements of the ensembles compared with the duty uniform alone.

Table 12. Minnesota Two-Hand Turning Test Results, Trooper Group

	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	32.0	3.5	7.6%
Ensemble B	39.1*	5.2	31.5%
Ensemble C	31.6	2.8	6.3%
Duty Uniform	29.8	1.8	

* The mean is statistically different from duty uniform mean on the paired t-test, $p<0.05$.

Key Findings:

- Ensemble B performed statistically different from the duty uniform condition.
- Ensembles A and C did not perform statistically different from the duty uniform condition.
- The percentage decrement values varied per ensemble condition:
  - Ensemble C performance decrement was 6.3%.
  - Ensemble A performance decrement was 7.6%.
  - Ensemble B performance decrement was 31.5%.

Discussion:

As with the HRV group, ensemble B had the slowest average performance. This is likely due to the two gloves worn per hand, compared with the other ensembles that used one glove per hand. Ensembles A and C performed similar to each other, most likely because both ensembles include the same one layer butyl glove type.

4.2.3 Combined Group Data Analysis—Gross Dexterity

Minnesota Two-Hand Turning Test time data were combined for both groups to determine if the times were affected by the interaction between the ensemble type and the experience level of the subjects. Repeated measures ANOVA tests were conducted using a main effect of "ensemble" and a between subjects effect of "experience level." Since the two groups of data were distinct data sets, only a test for any significant interaction effect was performed on the combined data.

Key Findings:

There was a statistically significant interaction effect ($p<0.05$) for the Minnesota Two-Hand Turning Test, indicating that ensemble type and experience together affected completion times. Neither factor alone had an impact on this test.

Discussion:

One possible explanation for this finding may be that the CB and special operations training made the Troopers more familiar with using gloves and increased their dexterity. In general, the Troopers' times were faster than the HRVs' times on this test.

4.3 Fine Dexterity

The O'Connor Fine Finger Dexterity Test identifies fine finger dexterity differences attributed to gloves or handwear. Glove testing configurations were identical to the gross dexterity testing.

This test required the subject to feel small objects, grasp them in a pincer grasp, and insert them into pre-drilled holes on the test board. The test was intended to demonstrate the fine finger dexterity performance decrement caused by the gloves. It was anticipated that wearing the CB suit and mask would have some impact on the results, though a smaller one than that caused by gloves. Therefore the dexterity testing was completed using the entire CB ensemble as it would be worn for response.

The data presented identify the statistical difference in ensemble performance when compared to the baseline duty uniform condition. All significance tests for each group were conducted as paired Student's t-tests.

4.3.1 HRV (Inexperienced) Group

Results Table:

Table 13 lists the HRV group's mean times and associated SDs for completing the O'Connor Fine Finger Dexterity Test by ensemble condition. Also presented are the performance decrements of the ensembles compared with the duty uniform alone.

Table 13. O'Connor Fine Finger Dexterity Test Results, HRV Group

	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	130.9*	17.3	47.5%
Ensemble B	207.9*	55.2	134.2%
Ensemble C	135.6	42.3	52.8%
Duty Uniform	88.8	11.0	

*The mean is statistically different from duty uniform mean on the paired t-test, $p<0.05$.

Key Findings:

- Ensembles A and B were statistically slower than the duty uniform alone condition.
- There was no statistical difference between Ensemble C and the duty uniform alone.
- The percentage decrement values varied per ensemble condition:
  - Ensemble A performance decrement was 47.5%.
  - Ensemble C performance decrement was 52.8%.
  - Ensemble B performance decrement was 134.2%.

Discussion:

The mean completion time for Ensemble C was greater than the mean time for Ensemble A. However, due to the large variance (square of the SD) in Ensemble C's data, the Student's t-test did not find a statistical difference between Ensemble C and the duty uniform. Due to the large difference in mean completion times, Ensemble B's mean time was statistically different from

the duty uniform's mean time. Ensemble B's time was most likely lengthened due to the double layer glove system, which impeded the fine dexterity required to pick up and move the small pins in the O'Connor Test.

4.3.2 Trooper (Experienced) Group

Table 14 lists the Trooper group's mean times and associated SDs for completing the O'Connor Fine Finger Dexterity Test by ensemble. Also presented are the performance decrements of the ensembles compared with the duty uniform alone.

Table 14. O'Connor Fine Finger Dexterity Test Results, Trooper Group

	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	117.4*	13.7	29.9%
Ensemble B	175.6*	17.4	94.3%
Ensemble C	126.0*	9.0	39.4%
Duty Uniform	90.4	7.4	

*The mean is statistically different than the duty uniform mean on the paired t-test, $p<0.05$.

Key Findings:

- All three ensembles were statistically slower than the duty uniform alone.
- The percentage decrement values varied per ensemble condition:
  - Ensemble A performance decrement was 29.9%.
  - Ensemble C performance decrement was 39.4%
  - Ensemble B performance decrement was 94.3%.

Discussion:

As with the HRV Group, the Troopers demonstrated that wearing gloves had a large detrimental impact on completion times for the O'Connor Test. Ensemble B's two-layer glove system appeared to have the greatest effect on the O'Connor Test completion time, as can be seen by the increase in completion time. In addition, the mask and ensemble most likely had an adverse impact on the results, though a much smaller one than the gloves.

4.3.3 Combined Group Data Analysis—Fine Dexterity

The O'Connor Fine Finger Dexterity Test times for the two groups were combined to determine whether the times were affected by the interaction between ensemble type and the test subjects' experience levels. Repeated measures ANOVA tests were conducted using a main effect of "ensemble" and a between subjects effect of "experience level." Since the two groups of data are distinct data sets, only a test for any significant interaction effect was performed on the combined data.

Key Findings:

No significant interaction effect was found between ensemble type and experience level for these test results.

Discussion:
In this study, differences in O'Connor Test values can only be attributed to differences in the ensemble conditions.

4.4 Gross Body Mobility

These tests assessed whether the combination of a suit, mask, gloves, and overboots affect the wearer's mobility. Adding any ensemble component can often have an impact on an individual's gross body mobility; however, separating out the individual component effect may not be possible since the assessment is completed on the entire ensemble. The gross body mobility tasks can isolate and allow discovery of the ensemble effects on body mobility. The results determine the decrement level and whether any significant differences exist between a particular ensemble and the baseline duty uniform.

Body mobility task details are provided in Section 2.4.1. Results are presented consecutively in all four categories for the HRV group in Section 4.4.1 and then for the Trooper group in Section 4.4.2. Student's t-tests were used to compare the performance of the ensembles relative to the duty uniform with the exception of the kneel and rise task, which is rated on pass/fail criteria. Individual group sections are followed by an analysis of the two groups' data combined.

4.4.1 HRV (Inexperienced) Group

4.4.1.1 Stepping Tasks

Results Table(s):
Table 15 lists the HRV group's mean distances and associated SDs for the stepping mobility tasks, including walking forward, walking backward, and side stepping.

Table 15. Stepping Mobility Task Results, HRV Group

		Walk Forward 5 Steps (cm)	Walk Backward 5 Steps (cm)	Side Step 5 Steps (cm)
Ensemble A	**Mean**	622.1 $^{\phi}$	525.6 $^{\gamma}$	491.8 $^{\phi}$
	SD	43.0	46.8	55.8
Ensemble B	**Mean**	628.2 $^{\phi}$	554.9 $^{\gamma}$	514.3 $^{\phi}$
	SD	32.6	40.5	37.8
Ensemble C	**Mean**	652.9 $^{\gamma}$	572.6 $^{\gamma}$	524.9 $^{\phi}$
	SD	24.1	41.0	45.2
Duty Uniform	**Mean**	629.8	515.7	537.0
	SD	76.4	70.2	66.2

There were no statistically significant differences between the duty uniform and tested ensembles on these tasks.

$^{\phi}$ The ensemble has a lower value than the duty uniform for that task.

$^{\gamma}$ The ensemble has a greater value than the duty uniform for that task.

Table 16 presents the performance decrement of the CB ensembles compared with the duty uniform.

Table 16. Performance Decrement for Stepping Tasks, HRV Group

	Ensemble	Performance Decrement vs. Duty Uniform
Walk Forward Five Steps	A	1.2%
	B	0.3%
Side Step Five Steps	A	9.2%
	B	4.4%
	C	2.3%

No statistically significant differences between ensembles were found. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Key Findings:

There were no statistically significant differences in performance between the CB ensembles and the duty uniform for any of the three stepping tasks.

Discussion:

Even though no statistically significant differences were found in the stepping task performances, some HRVs were able to step farther in a test ensemble than they did in their duty uniforms. The lack of statistical difference is not unusual, and is part of the expected variation between repeated trials. The ensembles provide enough range of motion to offset the effect of their added bulk.

4.4.1.2 Arm Tasks

Results Table(s):

Table 17 summarizes the HRV group's mean angles and associated SDs for the arm mobility tasks. This included upper arm abduction, upper arm forward extension, and upper arm backward extension.

Table 17. Arm Mobility Task Results, HRV Group

		Upper Arm Abduction (degrees)	Upper Arm Forward Extension (degrees)	Upper Arm Backward Extension (degrees)
Ensemble A	**Mean**	123.4 $^{\phi *}$	133.1 $^{\phi}$	42.5 $^{\phi}$
	SD	16.7	14.7	3.9
Ensemble B	**Mean**	140.5 $^{\phi}$	141.8 $^{\phi}$	52.1 $^{\gamma}$
	SD	3.4	6.3	6.0
Ensemble C	**Mean**	141.3 $^{\phi}$	148.7 $^{\phi}$	50.9 $^{\phi}$
	SD	7.7	5.3	9.1
Duty Uniform	**Mean**	146.6	153.6	51.7
	SD	7.3	3.4	8.7

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble has a lower value than the duty uniform for that task

$^{\gamma}$ The ensemble has a greater value than the duty uniform for that task

Table 18 presents the performance decrement of the CB ensembles compared with the duty uniform.

Table 18. Performance Decrement for Arm Mobility Tasks, HRV Group

	Ensemble	Performance Decrement vs. Duty Uniform
Upper Arm Abduction	A	18.8%*
	B	4.3%
	C	3.7%
Upper Arm Forward Extension	A	15.4%
	B	8.3%
	C	3.3%
Upper Arm Backward Extension	A	21.6%
	C	1.5%

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Key Findings:

Ensemble A's performance for upper arm abduction was statistically lower than that of the duty uniform.

Discussion:

Ensemble A was the only ensemble to exhibit a statistically significant decrement, as shown in upper arm abduction performance. Upper arm abduction involves moving the arm out to the side

of the body and upward as far as possible. Ensemble A was often bulky for the test participants. Though Ensemble A fit each subject properly for height, the ensemble was baggy, especially in the torso, due to the ensemble's design. For example, subjects often needed a larger size for their girth, which caused excess material to gather in the upper torso area. Therefore, a statistically significant difference in arm abduction range of motion for Ensemble A was found.

Neither of the other two tasks, upper arm forward extension or upper arm backward extension, demonstrated a statistically significant difference for any of the ensemble conditions. The HRV group was presumably less affected by the bulk of the ensembles when performing these tasks. However, most arm mobility tasks, with the exception of Ensemble B for upper arm backward extension, showed performance decrements compared with the duty uniform's performance.

4.4.1.3 Leg Tasks

Results Table(s):

Table 19 summarizes the HRV group's mean angles and associated SDs for the leg mobility tasks. This included upper leg forward extension, upper leg backward extension, and upper leg flexion.

Table 19. Leg Mobility Task Results, HRV Group

		Upper Leg Forward Extension (degrees)	Upper Leg Backward Extension (degrees)	Upper Leg Flexion (degrees)
Ensemble A	**Mean**	58.5 $^{\phi}$	41.2 $^{\gamma}$	71.8 $^{\phi}$
	SD	1.4	1.9	7.5
Ensemble B	**Mean**	61.3 $^{\gamma}$	40.5 $^{\gamma}$	75.8 $^{\phi}$
	SD	7.2	5.5	14.6
Ensemble C	**Mean**	60.7 $^{\phi}$	44.1 $^{\gamma}$ *	78.5 $^{\phi}$ *
	SD	7.6	3.8	12.7
Duty Uniform	**Mean**	61.0	39.6	86.3
	SD	12.8	6.6	11.1

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble has a lower value than the duty uniform for that task

$^{\gamma}$ The ensemble has a greater value than the duty uniform for that task.

Table 20 presents the performance decrement of the CB ensembles compared with the duty uniform.

Table 20. Performance Decrement for Leg Mobility Tasks, HRV Group

	Ensemble	Performance Decrement vs. Duty Uniform
Upper Leg Forward Extension	A	4.3%
	C	0.6%
Upper Leg Flexion	A	20.2%
	B	13.7%
	C	9.9%*

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Key Findings:

- Ensemble C's performance for upper leg flexion was statistically lower than that of the duty uniform alone.
- Ensemble C's performance for upper leg backward extension was statistically higher for ensemble C than that of the duty uniform.

Discussion:

It is not clear why upper leg backward extension provided significantly increased performance in Ensemble C than in the duty uniform. One possible, but unlikely, reason is that the subjects may have been more limber when performing tests in Ensemble C. However, randomization of ensembles reduced this possibility. Being more limber is an unlikely cause, since none of the other leg movements and few of the arm movements had means greater in Ensemble C than in the duty uniform. Ensemble C was a two-piece ensemble with separate trousers, allowing (by observation and subjects' comments) a fair degree of mobility. The other ensembles had upper leg backward extension scores within a few degrees of each other and of the duty uniform.

Upper leg flexion performance was statistically lower for Ensemble C than for the duty uniform. Thus, Ensemble C restricted leg mobility for this task more than the duty uniform. This finding is interesting in light of the statistically greater upper leg backward mobility of the same ensemble. This indicates there is a difference in mobility between the hip and knee areas (the two areas tested in these tasks) in this ensemble. In addition, Ensemble C had the highest performance for this task, but was the only one that differed statistically from the duty uniform. The difference likely resulted from a combination of the range and size of individual subject's measurements and the means and variances for each ensemble.

4.4.1.4 Bending Tasks

Results Table:

Bending tasks included standing trunk flexion and kneel and rise tasks. Table 21 summarizes the HRV group's mean distances, SDs, and performance decrements for the standing trunk flexion.

Table 21. Standing Trunk Flexion Results, HRV Group

	Mean (cm)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	19.8 ϕ [a]	10.4	142.8% [b]
Ensemble B	10.0 ϕ	9.8	22.9%
Ensemble C	9.9 ϕ	9.9	20.9%
Duty Uniform	8.2	9.8	

[a] The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

[b] The mean associated with this decrement is statistically different from the duty uniform mean.

ϕ The ensemble had a lower value than the duty uniform for that task.

Key Findings:

- **Standing Trunk Flexion:** Ensemble A's performance for standing trunk flexion was statistically lower than the duty uniform alone.
- **Kneel and Rise:** All four test conditions (CB ensembles and duty uniform) were rated a "3" (out of 3), or "can rise from kneeling position with no assistance".

Discussion:

Standing trunk flexion uses a mean calculation for ensemble performance, which can be compared with the duty uniform alone. A lower score indicates superior performance because the measurement represents the distance between the fingertips and the floor. Greater resistance to bending at the waist would result in a higher value. The bulk, sizing scheme, and one-piece design of Ensemble A most likely contributed to significantly lower bending mobility compared with the duty uniform. Ensemble A's bulk tended to gather at the waist unless the subject moved it around to another location, thereby affecting bending at the waist.

Kneel and rise uses a rating scale for the degree of success and independence a subject achieves in kneeling and then standing again. The rating scale is as follows:

0 = Cannot get down on both knees
1 = Cannot rise from kneeling position
2 = Can rise from kneeling position but needs to grasp object (for example, a chair)
3 = Can rise from kneeling position without help

All four test conditions were rated a "3", or "can rise from kneeling position with no assistance". Although the ensembles tended to be bulky to varying degrees, none caused enough resistance or interference to mobility. All subjects in this group commented that it was easy to complete this task.

4.4.2 Trooper (Experienced) Group

4.4.2.1 Stepping Tasks

Results Table(s):

Tables 22 lists the Trooper group's mean distances and associated SDs for the stepping mobility tasks, including walking forward, walking backward, and side stepping.

Table 22. Stepping Mobility Task Results, Trooper Group

Stepping Tasks		Walk Forward 5 Steps (cm)	Walk Backward 5 Steps (cm)	Side Step 5 Steps (cm)
Ensemble A	**Mean**	715.7 $^{\gamma}$	621.1 $^{\phi}$	600.6 $^{\phi}$
	SD	46.1	36.1	42.1
Ensemble B	**Mean**	720.2 $^{\gamma}$	620.0 $^{\phi}$	578.3 $^{\phi}$
	SD	54.2	44.3	51.4
Ensemble C	**Mean**	725.8 $^{\gamma}$	653.0 $^{\gamma}$	618.1 $^{\phi}$
	SD	31.0	26.3	39.3
Duty Uniform	**Mean**	695.8	623.5	620.3
	SD	92.1	81.0	54.3

There were no statistically significant differences between the duty uniform and the tested ensembles on these tasks.

$^{\phi}$ The ensemble had a lower value than the duty uniform for that task;

$^{\gamma}$ The ensemble had a greater than the duty uniform for that task.

Table 23 presents the performance decrement of the CB ensembles compared with the duty uniform.

Table 23. Performance Decrement for Stepping Tasks, Trooper Group

Task	Ensemble	Performance Decrement vs. Duty Uniform
Walk Backward Five Steps	A	0.4%
	B	0.6%
Side Step Five Steps	A	3.3%
	B	7.3%
	C	0.4%

No statistically significant differences between ensembles were found. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Key Findings:

There were no statistically significant differences in performance between the CB ensembles and the duty uniform for any of the three stepping tasks.

Discussion:
Even though no statistically significant differences were found in the stepping task performances, some HRV test participants were able to step farther in a test CB ensemble than they did wearing their duty uniforms. The lack of statistical difference is not unusual, and is part of the expected variation between repeated trials. The ensembles provided enough range of motion to offset the effect of their added bulk.

4.4.2.2 Arm Tasks

Results Table(s):
Table 24 summarizes the Trooper group's mean angles and associated SDs for the arm mobility tasks, including upper arm abduction, upper arm forward extension, and upper arm backward extension.

Table 24. Arm Mobility Task Results, Trooper Group

Arm Tasks		Upper Arm Abduction (degrees)	Upper Arm Forward Extension (degrees)	Upper Arm Backward Extension (degrees)
Ensemble A	**Mean**	158.5 $^{\phi}$ *	166.9 $^{\phi}$	46.1 $^{\phi}$
	SD	4.8	6.4	7.0
Ensemble B	**Mean**	159.8 $^{\phi}$	166.1 $^{\phi}$ *	54.8 $^{\gamma}$ *
	SD	7.5	5.6	4.7
Ensemble C	**Mean**	157.1 $^{\phi}$	164.6 $^{\phi}$ *	49.3 $^{\phi}$
	SD	7.5	12.1	3.7
Duty Uniform	**Mean**	162.6	173.5	50.8
	SD	6.2	8.8	5.1

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a lower value than the duty uniform for that task.

$^{\gamma}$ The ensemble had a greater value than the duty uniform for that task.

Table 25 presents the performance decrement of the CB ensembles compared with the duty uniform.

Key Findings:
- Ensemble A's performance for upper arm abduction was statistically lower than that of the duty uniform alone.
- Ensemble B's and Ensemble C's performances for upper arm forward extension were statistically lower than the performance of the duty uniform alone.
- Ensemble B's performance for upper arm backward extension was statistically higher than that of the duty uniform alone.

Table 25. Performance Decrement for Arm Mobility Tasks, Trooper Group

Task	Ensemble	Performance Decrement vs. Duty Uniform
Upper Arm Abduction	A	2.6%*
	B	1.7%
	C	3.5%
Upper Arm Forward Extension	A	3.9%
	B	4.5%*
	C	5.4%*
Upper Arm Backward Extension	A	10.3%
	C	3.0%

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Discussion:

All three arm tasks demonstrated some statistically significant differences in the Trooper group. Upper arm abduction was statistically lower in Ensemble A than in the duty uniform alone. Ensemble A's variance for this task was less than one-half the variance of the other two ensembles and most likely contributed to the statistical significance for this configuration. In addition, abduction involves moving the arm out to the side of the body and upward as far as possible. Ensemble A was often bulky for the test participants. Though Ensemble A fit each subject properly for height, the ensemble was baggy, especially in the torso, due to the ensemble's design. For example, subjects often needed a larger size for their girth, which caused excess material to gather in the upper torso area. Therefore, a statistically significant difference in arm abduction range of motion for Ensemble A was found.

Upper arm forward extension was statistically lower in Ensembles B and C than in the duty uniform. In this task, resistance in the design of Ensembles B and C appears to be the cause of the significant statistical difference from the duty uniform.

Ensemble B performed statistically better than the duty uniform for upper arm backward extension, indicating that the subjects had greater backward extension when wearing Ensemble B. Since the presentation order of all the ensembles was randomly assigned, it is unlikely that all of the Troopers were the most limber by the time Ensemble B was tested. All subjects were shown how to properly perform this task, and the evaluator ensured that the motion was conducted correctly each time. Therefore, the reason for Ensemble B's significantly greater performance on this task is unclear.

In the Trooper group, most of the arm mobility tasks showed a performance decrement for all of the ensembles compared with the duty uniform alone. However, only decrements associated with statistically significant differences are summarized in this report.

4.4.2.3 Leg Tasks

Results Table(s):

Table 26 summarizes the Trooper group's mean angles and associated SDs for the leg mobility tasks, including upper leg forward extension, upper leg backward extension, and upper leg flexion.

Table 26. Leg Mobility Task Results, Trooper Group

Leg Tasks		Upper Leg Forward Extension (degrees)	Upper Leg Backward Extension (degrees)	Upper Leg Flexion (degrees)
Ensemble A	**Mean**	69.8 $^{\phi}$	44.8 $^{\gamma}$	83.6 $^{\phi}$
	SD	5.3	5.7	4.0
Ensemble B	**Mean**	68.6 $^{\phi}$	47.2 $^{\gamma}$	80.3 $^{\phi}$ *
	SD	6.6	8.5	7.2
Ensemble C	**Mean**	66.8 $^{\phi}$	45.3 $^{\gamma}$	84.3 $^{\phi}$
	SD	3.4	5.3	2.4
Duty Uniform	**Mean**	71.4	44.1	91.3
	SD	10.7	9.3	9.4

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a lower value than the duty uniform for that task.

$^{\gamma}$ The ensemble had a greater value than the duty uniform for that task.

Table 27 presents the performance decrement of the CB ensembles compared with the duty uniform.

Table 27. Performance Decrement for Leg Mobility Tasks, Trooper Group

Task	Ensemble	Performance Decrement vs. Duty Uniform
Upper Leg Forward Extension	A	2.3%
	B	4.1%
	C	6.9%
Upper Leg Flexion	A	9.3%
	B	13.8%*
	C	8.3%

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores higher than the duty uniform score.)**

Key Finding(s):

Ensemble B's performance for upper leg flexion was statistically lower than that of the duty uniform alone.

Discussion:
Upper leg flexion performance was statistically lower for Ensemble B than for the duty uniform. Thus, Ensemble B restricted leg mobility for this task more than the duty uniform. Possible explanations for Ensemble B's performance include its bulk and one-piece design. This indicates there is a difference in mobility between the hip and knee areas (the two areas tested in these tasks) for Ensemble B.

4.4.2.4 Bending Tasks

Results Table(s):
Bending tasks included standing trunk flexion and kneel and rise tasks. Table 28 summarizes the Trooper group's mean distances, SDs, and performance decrements for standing trunk flexion.

Table 28. Standing Trunk Flexion Results, Trooper Group

Standing Trunk Flexion	Mean (cm)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	7.5 ϕ [a]	3.3	373.9% [b]
Ensemble B	2.6 ϕ	3.1	63.2%
Ensemble C	2.5 ϕ	3.1	58.0%
Duty Uniform	1.6	3.2	

[a] The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.
[b] The mean associated with this decrement is statistically different from the duty uniform mean.
ϕ The ensemble had a lower value than the duty uniform for that task.

Key Finding(s):
Ensemble A's performance for standing trunk flexion was statistically lower than that of the duty uniform alone.

Discussion:
Standing trunk flexion uses a mean calculation for ensemble performance, which is used to compare it with duty uniform performance. A lower score indicates superior performance because the measurement represents the distance between the fingertips and the floor. Greater resistance to bending at the waist would result in a higher value. Ensemble A was the only ensemble to have a statistical difference, demonstrating lower mobility than the duty uniform on the standing trunk flexion task. The bulk, sizing scheme, and one-piece design of Ensemble A most likely contributed to significantly lower bending mobility than the duty uniform. Ensemble A's bulk tended to gather at the waist unless the subject moved the ensemble around to another location, thereby affecting bending at the waist.

As previously stated, kneel and rise uses a rating scale for the degree of success and independence a subject achieves in kneeling and then standing again. In every test condition, the Troopers were able to kneel and stand up again without assistance. Therefore, all three

ensembles were rated "3". Despite the bulk of the various ensembles, no ensemble interfered with Troopers' bending mobility. All Troopers commented that it was easy to complete this task.

4.4.3 Combined Group Data Analysis—Gross Body Mobility

Gross body mobility means for the HRV and Trooper groups were combined to allow statistical testing for any interaction effects. The goal was to determine statistically whether the means for body mobility were affected by the interaction between ensemble type and the experience levels of the subjects.

Key Findings:

Upper arm abduction demonstrated an interaction effect between ensemble type and experience level combined. Neither ensemble type nor experience level alone had an impact.

Discussion:

In this task, there is no obvious reason to explain why experience level would interact with ensemble type. The HRV and Trooper groups were both reasonably physically fit. The HRVs were younger, but the Troopers achieved means for this task that were approximately 20 degrees greater than the HRVs' means. These data appear contradictory, but there are instances when interaction effects are significant for no logical explanation. It appears to be the case here, as the interaction cannot be easily explained.

4.5 Mission Scenarios

4.5.1 HRV (Inexperienced) Group

4.5.1.1 Scenario 1 – Perimeter Control

Results Table(s):

Table 29 summarizes the HRV group's mean time, SDs, and performance decrement for the perimeter control mission scenario.

Table 29. Scenario 1 (Perimeter Control) Results, HRV Group

Scenario 1—Perimeter Control	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	448.8 $^{\phi}$	98.3	22.6%
Ensemble B	471.8 $^{\phi}$	100.5	28.9%
Ensemble C	446.5 $^{\phi}$	89.4	22.0%
Duty Uniform	366.0	42.4	

None of the means were statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a lower value than the duty uniform for that task.

Key Finding(s):
For the perimeter control scenario, there were no statistical differences in time performance between the CB ensembles and the duty uniform.

Discussion:
The variances in the magnitude of the mean measurements for each of the CB ensembles are more than double the variance of the duty uniform. These large variances compared with the duty uniform variance are the likely reason for the lack of statistically significant differences.

4.5.1.2 Scenario 2 – Tactical
The tactical scenario was divided into eight timed subtasks in addition to the total time required to complete the scenario. This allowed for comparison of individual task completion within the different ensembles. Table 30 summarizes the timed subtasks used in this scenario.

Table 30. List of Tactical Scenario Subtasks

Scenario 2 Sub-Task	Description of Tasks Accomplished in Time Block (Times are consecutive - no gaps.)
Time 1	From timer start through issuing commands to "assailant" .
Time 2	Drop M4 (to be caught by sling), draw 9 mm, swap magazine from case on belt to 9 mm.
Time 3	Stand next to "assailant", holster 9 mm, restrain "assailant" with handcuffs.
Time 4	Frisk "assailant," stand him up
Time 5	Radio to team member that you are exiting with "assailant" in custody.
Time 6	Escort "assailant" out into hallway, hand "assailant" off, clear hallway.
Time 7	Enter next area, clear area, drag downed officer to safe area.
Time 8	Clear malfunction in M4, run to wall, scale wall. Timer stopped.
Total Time	Tactical scenario total consecutive elapsed time.

Results Table(s):
Table 31 lists the HRV group's mean times and associated SDs for the tactical scenario, including each subtask and total time.

Table 31. Scenario 2 (Tactical) Results by Ensemble, HRV Group

Scenario 2 Subtask	Ensemble A		Ensemble B		Ensemble C		Duty Uniform	
	Mean (s)	SD	Mean (s)	SD	Mean (s)	SD	Mean (s)	SD
Time 1	29.0 $^{\phi}$	2.4	28.5 $^{\phi}$	2.4	31.0 $^{\phi}$	6.9	27.0	5.2
Time 2	17.3 $^{\phi}$	9.0	23.3 $^{\phi}$	12.0	13.3 $^{\gamma}$	6.1	15.3	4.6
Time 3	17.0 $^{\gamma}$	10.8	15.3 $^{\gamma}$	5.6	19.3 $^{\gamma}$	2.6	21.0	9.7
Time 4	19.0 $^{\phi}$	10.5	18.3 $^{\phi}$	9.2	18.8 $^{\phi}$	15.7	7.0	4.8
Time 5	7.0 $^{\gamma}$ *	3.4	7.3 $^{\gamma}$	5.9	16.5 $^{\phi}$	3.1	8.5	3.8
Time 6	10.8 $^{\phi}$	3.5	15.8 $^{\phi}$	11.1	9.3 $^{\gamma}$	3.9	9.8	4.5
Time 7	20.5 $^{\phi}$	4.8	15.3 $^{\phi}$	2.1	12.8 $^{\phi}$	3.2	11.5	4.9
Time 8	27.3 $^{\phi}$	7.6	23.5 $^{\gamma}$	4.7	25.5 $^{\phi}$	4.8	24.0	1.2
Total Time	**147.8 $^{\phi}$ ***	**10.5**	**147.0 $^{\phi}$**	**25.5**	**146.3 $^{\phi}$ ***	**17.9**	**124.0**	**6.1**

*The mean is significantly different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a greater (slower) value than the duty uniform for that task.

$^{\gamma}$ The ensemble had a lower (quicker) value than the duty uniform for that task.

Table 32 lists the performance decrements of the CB ensembles when compared with those of the duty uniform.

Table 32. Performance Decrement for Scenario 2 Tasks (Tactical), HRV Group

Subtask Times and Total Time	Ensemble	Performance Decrement vs. Duty Uniform
Scenario 2, Time 1	A	7.4%
	B	5.6%
	C	14.8%
Scenario 2, Time 2	A	13.1%
	B	52.5%
Scenario 2, Time 4	A	171.4%
	B	160.7%
	C	167.9%
Scenario 2, Time 5	C	94.1%
Scenario 2, Time 6	A	10.3%
	B	61.5%
Scenario 2, Time 7	A	78.3%
	B	32.6%
	C	10.9%
Scenario 2, Time 8	A	13.5%
	C	6.3%
Scenario 2, Total Time	A	19.2%*
	B	18.5%
	C	17.9%*

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores better than the duty uniform score).**

Key Finding(s):

- Ensemble A was statistically faster than the duty uniform for Time 5 (radio to team member that you are exiting with the "assailant" in custody).
- Both Ensembles A and C were statistically slower in running the whole scenario than the duty uniform alone.

Discussion:

Ensemble A was statistically faster than the duty uniform for Time 5 in this scenario, which included radioing a team member that the test subject was exiting with an "assailant" in custody.

The total time to complete the scenario also demonstrated significant differences on the paired Student's t-tests. Ensembles A and C took statistically longer to run the whole scenario than the duty uniform. Ensemble B's mean time was very close to that of Ensembles A and C, but it was not statistically different, most likely due to its larger variance. This scenario is a dynamic test of vision, dexterity, strength, and speed. All of these factors can be affected by a mask, gloves, and a bulky ensemble.

4.5.1.3 Scenario 3 – Crime Scene Investigation

Results Table(s):

Table 33 summarizes the HRV group's mean times, SDs, and performance decrements for the crime scene investigation mission scenario.

Table 33. Scenario 3 Results (Crime Scene Investigation), HRV Group

Scenario 3— Crime Investigation	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	499.8 $^{\phi}$	92.8	1.9%
Ensemble B	577.3 $^{\phi\ a}$	124.6	17.7% ^{b}
Ensemble C	492.0 $^{\phi}$	47.4	0.3%
Duty Uniform	490.5	98.7	

[a] The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

[b] The mean associated with this decrement is statistically different from the duty uniform mean.

$^{\phi}$ The ensemble had a greater (slower) value than the duty uniform for that task.

Key Finding(s):

Ensemble B was statistically slower than the duty uniform.

Discussion:

This scenario required the test subjects to don 10 to 15 pairs of latex gloves over the chemical protective gloves or bare hand depending on the configuration. This was to simulate techniques used to avoid cross-contamination of evidence. However, as the subjects prepared for this scenario, it became obvious that no more than six pairs of latex gloves could be worn. Donning

more than six pairs caused the gloves to rip and tear, contaminating them and making them unusable for evidence collection.[25] In the duty uniform condition, where no additional gloves are worn, the subjects could consistently don six pairs of latex gloves. For the ensemble conditions, between three and six pairs were donned. The number of pairs of latex gloves donned depended on the size of the subjects' hands rather than the type of chemical protective gloves the subjects wore. When fewer than six pairs were donned, the subjects simulated stripping a pair of gloves from their hands at the appropriate points in the scenario until the number of gloves equaled the number of evidence items. After that, the subjects removed an actual pair of latex gloves at each remaining point.[26]

Ensemble B used a two-part glove system, which combined with three to six pairs of latex gloves, limited hand mobility and dexterity as demonstrated by subject accounts and observation. Lack of mobility and dexterity were sources of the extended time to complete the scenario in Ensemble B.

The latex gloves affected Ensembles A and C and the duty uniform condition equally. The three conditions had similar completion times, although the latex gloves were worn over bare hands with the duty uniform and over butyl gloves with Ensembles A and C.

4.5.2 Trooper (Experienced) Group

4.5.2.1 Scenario 1 – Perimeter Control

Results Table(s):

Table 34 summarizes the Trooper group's mean times, SDs, and performance decrements for the perimeter control mission scenario.

Table 34. Scenario 1 Results (Perimeter Control), Trooper Group

Scenario 1— Perimeter Control	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	236.3 $^{\phi}$	3.6	22.9%
Ensemble B	240.5 $^{\phi}$	51.8	25.1%
Ensemble C	224.0 $^{\phi}$	56.2	16.5%
Duty Uniform	192.3	38.6	

None of the means were statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Performance decrements are presented for information only, since no statistically significant differences were found.

$^{\phi}$ The ensemble had a greater (slower) value than the duty uniform for that task.

[25] The latex gloves were sized as "one size fits all".

[26] The Troopers indicated that in practice, given the tearing and the difficulty in donning multiple pairs of gloves, they would don approximately four pairs of latex gloves. If more pairs of latex gloves were necessary, they would retreat to the staging area and don more gloves before proceeding with evidence collection.

Key Finding:
There were no statistical differences in completion time for the perimeter control scenario between the CB ensembles and the duty uniform alone.

Discussion:
There were no significant differences between the CB ensembles and the duty uniform for the perimeter control scenario. Although the CB ensemble condition times were approximately 15-25% longer than the duty uniform times, the variances observed in the four testing conditions most likely resulted in no significant difference between the CB ensembles and the duty uniform.

4.5.2.2 Scenario 2 – Tactical

Results Table(s):
Table 35 lists the Trooper group's mean times and associated SDs for the tactical scenario, including each subtask and total time.

Table 35. Scenario 2 Results by Ensemble (Tactical), Trooper Group

Scenario 2 Subtask	Ensemble A		Ensemble B		Ensemble C		Duty Uniform	
	Mean (s)	SD	Mean (s)	SD	Mean (s)	SD	Mean (s)	SD
Time 1	20.0 $^{\phi}$ *	1.6	16.8 $^{\phi}$	1.5	20.8 $^{\phi}$ *	1.5	15.3	1.0
Time 2	13.3 $^{\phi}$	2.5	10.5 $^{\gamma}$	2.4	19.0 $^{\phi}$	6.8	10.8	3.7
Time 3	21.8 $^{\phi}$	8.3	21.3 $^{\phi}$ *	2.6	28.8 $^{\phi}$ *	9.3	15.0	1.2
Time 4	6.8 $^{\phi}$	4.6	4.5 $^{\gamma}$	2.9	5.3 $^{\gamma}$	3.7	5.8	3.3
Time 5	4.0 $^{\phi}$	2.6	3.3 $^{\phi}$	1.5	8.5 $^{\phi}$	3.0	2.8	1.5
Time 6	6.0 $^{\phi}$	1.6	3.8 $^{\gamma}$	1.0	12.3 $^{\phi}$	7.1	4.8	1.0
Time 7	13.5 $^{\phi}$ *	3.1	11.0 $^{\phi}$	1.4	14.5 $^{\phi}$	9.7	8.5	1.3
Time 8	17.8 $^{\phi}$ *	1.7	15.0 $^{\phi}$	1.2	17.8 $^{\phi}$	5.3	13.0	1.2
Total Time	**103.0 $^{\phi}$ ***	**13.9**	**86.0 $^{\phi}$**	**8.1**	**126.8 $^{\phi}$ ***	**26.8**	**75.8**	**2.2**

*The mean is statistically different from the duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a greater (slower) value than the duty uniform for that task

$^{\gamma}$ The ensemble had a lower (quicker) value than the duty uniform for that task.

Table 36 compares the performance decrements of the CB ensembles and the duty uniforms.

Table 36. Performance Decrement for Scenario 2 (Tactical) Tasks, Trooper Group

Scenario 2 Subtask	Ensemble	Performance Decrement vs. Duty Uniform
Time 1	A	31.1%*
	B	9.8%
	C	36.1%*
Time 2	A	23.3%
	C	76.7%
Time 3	A	45.0%
	B	41.7%*
	C	91.7%*
Time 4	A	17.4%
Time 5	A	45.5%
	B	18.2%
	C	209.1%
Time 6	A	26.3%
	C	157.9%
Time 7	A	58.8%*
	B	29.4%
	C	70.6%
Time 8	A	36.5%*
	B	15.4%
	C	36.5%
Total Time	A	36.0%*
	B	13.5%
	C	67.3%*

*The mean associated with this decrement is statistically different from the duty uniform mean on the paired t-test, $p<0.05$. Ensembles and tasks listed are those that had a performance decrement vs. the duty uniform. **(Other ensembles and/or tasks not listed had scores better than the duty uniform score).**

Key Finding(s):

- Ensembles A and C were statistically slower than the duty uniform for Time 1 (from timer start through issuing commands to the "assailant").
- Ensembles B and C were statistically slower than the duty uniform for Time 3 (stand next to the "assailant",' holster the 9 mm, restrain the "assailant" with handcuffs).
- Ensemble A was statistically slower than the duty uniform for Time 7 (enter next area, clear area, drag downed officer to safe area).
- Ensemble A was statistically slower than the duty uniform for Time 8 (clear malfunction in M4, run to wall, scale wall).
- Both ensembles A and C were statistically slower for the whole scenario than the duty uniform.

Discussion:
The Troopers completed the first subtask, Time 1, statistically slower in Ensembles A and C than in the duty uniform. Ensembles B and C performed statistically slower than the duty uniform for Time 3. Time 3 included standing next to an "assailant", holstering the handgun, approaching the "assailant", and restraining him with handcuffs. The increased completion time would be expected, given the required manipulation of a handgun and handcuffs while wearing gloves. However, Ensemble A did not exhibit the same statistical difference in performance. Ensemble A's data exhibited a mean time between the other ensembles' scores; however, the variance (the square of the SD) was much higher than Ensemble B's. This large variance is most likely attributed to the lack of statistical significance observed.

A similar situation arose in Time 7, which included clearing a hallway and dragging a downed "officer". Troopers wearing Ensemble A performed this subtask statistically slower than the duty uniform. Ensemble C's mean was actually higher than Ensemble A's, but Ensemble C's spread of individual scores created a large variance, which prevented finding statistical significance for Ensemble C. Given Ensemble A's bulk and restriction, it is not surprising that the Troopers took statistically longer to complete this subtask in Ensemble C than in the duty uniform.

Ensemble A exhibited a significantly slower mean time than the duty uniform for Time 8, which included clearing a rifle malfunction, re-slinging the weapon, running to a wall, and scaling the wall. Ensemble A's bulk, restriction, and poor visibility contributed to the statistical significance observed. Ensemble C had a similar mean, but as with Time 7, it had a much larger variance due to the range of the individual Troopers' times, and was not statistically different from the duty uniform mean.

The Troopers took statistically longer to run the entire scenario in Ensemble A and in Ensemble C than in the duty uniform. The scenario is a dynamic test of vision, dexterity, strength, and speed. All of these factors are affected by a mask, gloves, and a bulky ensemble.

Troopers took almost four times longer to perform Time 5 in Ensemble C than in the duty uniform, but the difference was not found to be statistically significant. This is likely due to the small numeric values for Time 5 and the relatively (proportionally) large variance for all of the ensembles on this time, especially Ensemble C. In cases where numeric values are small, a very small variance and a large difference between values are required to find significance with a sample size of four.

It should be noted that the evaluator was careful to time all tasks at the same point in every trial, and to instruct subjects to conduct the scenario the same way each time they ran it. These factors were reduced or eliminated as causes for differing subtask times.

4.5.2.3 Scenario 3 – Crime Scene Investigation
Results Table(s):
Table 37 summarizes the Trooper group's mean times, SDs, and performance decrements for the crime scene investigation mission scenario.

Table 37. Scenario 3 Results (Crime Scene Investigation), Trooper Group

Scenario 3—Crime Investigation	Mean (s)	SD	Performance Decrement vs. Duty Uniform
Ensemble A	402.0 $^{\phi}$	97.1	1.6%
Ensemble B	468.5 $^{\phi}$	102.8	18.4%
Ensemble C	398.3 $^{\phi}$	80.7	0.6%
Duty Uniform	395.8	78.3	

None of the means were statistically different from duty uniform mean on the paired t-test, $p<0.05$.

$^{\phi}$ The ensemble had a greater (slower) value than the duty uniform for that task.

Key Finding(s):

No statistical differences were found between the CB ensembles and the duty uniform in time performance for the crime scene investigation scenario.

Discussion:

Like the HRV group, the Troopers were only able to don three to six pairs of latex gloves during this scenario, depending on the physical size of the subject's hands. The subjects simulated stripping a pair of gloves from their hands, as necessary, at the appropriate points in the scenario.

No statistical differences between mean ensemble completion times were found for this scenario. Variability in the means for each ensemble is the likely reason for a lack of statistical significance between ensemble scores. The latex gloves appeared to have the same effect on performance for all of the ensembles, despite being used with bare hands for the duty uniform condition and with chemical protective gloves for the CB ensemble conditions.

4.5.3 Combined Group Data Analysis—Mission Scenarios

Mean scores for the mission scenarios were combined for the HRV and Trooper groups to test statistically if an interaction existed between ensemble type and the subject's experience level. If no interaction was found, the differences between ensembles for scenario completion time in each group would be due to ensemble type alone.

Key Finding(s):

No interaction effects were found for any of the scenarios, including Scenario 2's subtask times.

5 Summary of Results

Two groups, each comprised of four male subjects, took part in this Evaluation. The test subjects' performance in the three different CB ensemble conditions was compared with a baseline duty uniform configuration. Ensembles used in this evaluation are described in Sections 2.2 and 2.3. A summary is provided in Table 38.

Table 38. Ensemble Type Descriptions

Ensemble Type	Ensemble Description
Ensemble A 	Ensemble A consisted of: ▪ Suit A (impermeable suit) ▪ APR ▪ Standard butyl gloves ▪ Butyl overboots
Ensemble B 	Ensemble B consisted of: ▪ Suit B (SPM suit) ▪ APR ▪ Two-piece glove system ▪ Light-weight impermeable overboots
Ensemble C 	Ensemble C consisted of: ▪ Suit C (air permeable suit) ▪ APR ▪ Standard butyl gloves ▪ Butyl overboots
Duty Uniform	The HRV group wore their ACUs. The Trooper group wore a BDU and combat boots. The duty uniform trousers and boots were worn under each CB suit ensemble.[27]

[27] Some performance differences may have been due to the different design, materials, and fit of the ACU compared to the BDU. However, all performance changes for a subject in a particular ensemble are expressed as a percentage relative to that subject. In other words, the overall benefit or disadvantage of wearing the duty uniform by itself is still captured for all three CB ensembles.

Unless otherwise noted, all comparisons below are based on the statistical analyses between and/or within the HRV group and the Trooper group.

Donning:

- Ensemble design impacts donning time and ease for each test group.
- Donning times for SCBA were longer than for the APR due to additional buckles and straps required to secure the SCBA. The only exception was seen for Ensemble B where the APR took longer to don. This was attributed to the interaction between the APR and Ensemble B's hood design, which was separate from the suit and required multiple steps to don. Although these observations are true for both test groups, they are only statistically significant[28] for the HRV group. This indicates that only the HRV group was able to don the SCBA statistically faster than they were able to don the APR.
- The HRV group donned Ensemble C statistically faster than Ensemble A while wearing either the SCBA or APR respirators.
- Both test groups rated Ensemble C the easiest to don with either respirator.

Doffing:

- The SCBA doffing times for Ensemble C were statistically faster than the times for Ensembles A and B for both test groups.
- The APR doffing times for Ensemble C were statistically faster than those for Ensemble A for the HRV group.
- Both groups rated Ensemble C as the easiest to doff with either respirator.

Combined HRV and Trooper Data for Donning and Doffing:

- There were statistically significant interaction effects for donning and doffing times with the SCBA for the combined HRV and Trooper data sets. This indicates that ensemble type and experience affected donning and doffing times while neither factor alone had an impact.
- There were no statistically significant interaction effects for donning and doffing times with the APR for the combined HRV and Trooper data sets.

Gross Dexterity: Minnesota Two-Handed Turn Test:

- For the HRV group, all three ensembles had statistically slower times to complete the gross dexterity test than the duty uniform.
- For the Trooper group, Ensemble B had statistically slower times than the duty uniform for the gross dexterity test.
- Gloves had a large adverse impact on performance, decreasing hand dexterity and tactility.
- Ensemble B (a two-layer glove system) had the longest times when compared with Ensemble A (a single layer glove system), Ensemble C (a single layer glove system), and the duty uniform (bare hand).

[28] For a review of statistical significance as it pertains to this analysis, refer to Section 4.1.

Combined HRV and Trooper Data for Gross Dexterity:

- There was a statistically significant interaction effect for gross dexterity for the combined HRV and Trooper data sets. This indicates that ensemble type and experience together affected completion times while neither factor alone had an impact.

Fine Dexterity: O'Connor Fine Finger Dexterity Test:

- For the HRV group, Ensembles A and B had statistically slower times to complete the fine dexterity tests than the duty uniform.
- For the Trooper group, all three ensembles had statistically slower times to complete the fine dexterity tests than the duty uniform.

Combined HRV and Trooper Data for Fine Finger Dexterity

- No statistically significant interaction effect was found between ensemble type and experience level. This indicates that the statistical differences in fine finger dexterity values in this study can only be attributed to differences in the ensemble conditions.

Gross Body Mobility Stepping Tasks: Forward Step, Backward Step, and Side Step:

- No statistical differences in the three stepping body mobility tasks were found for the ensembles when compared with the duty uniform.

Gross Body Mobility Arm Tasks: Upper Arm Abduction, Upper Arm Forward Extension, and Upper Arm Backward Extension:

- For both test groups, Ensemble A's upper arm abduction performance was statistically lower than that of the duty uniform alone. This indicates that Ensemble A's design limited the ability of the test subjects to move their arms out to the side of their bodies and upward.
- For the Trooper group, Ensembles B and C had upper arm forward extension performances, which were statistically lower than those of the duty uniform alone. This indicates that the designs of Ensembles B and C limited the ability of the test subjects to move their arms forward and upward.
- For the Trooper group, Ensemble B's upper arm backward extension was statistically higher than that of the duty uniform alone. This indicates that Ensembles B's design increased the test subjects' ability to move their arms backward and upward.

Combined HRV and Trooper Data for the Gross Body Mobility Arm Tasks:

- Upper arm abduction demonstrated a statistically significant interaction effect between ensemble type and experience level, while neither factor alone had an impact.

Gross Body Mobility Leg Tasks: Upper Leg Forward Extension, Upper Leg Backward Extension, and Upper Leg Flexion:

- For the HRV group, Ensemble C's upper leg flexion performance was statistically lower than that of the duty uniform alone. This indicates that Ensemble C's design limited the ability for the test subjects to raise their legs upward with their knees bent.
- For the HRV group, Ensemble C's upper leg backward extension performance was statistically higher than that of the duty uniform alone. This indicates that Ensemble C's design increased the test subjects' ability to move their legs backward and upward.

- For the Trooper group, Ensemble B's upper leg flexion performance was statistically lower than that of the duty uniform alone. This indicates that the Ensemble B's design limited the ability for the test subjects to raise their legs upward with their knees bent.

Combined HRV and Trooper Data for the Gross Body Mobility Leg Tasks:

- No statistically significant interaction effect was found between ensemble type and experience level. This indicates that the statistical differences in gross body mobility leg tasks in this study can only be attributed to differences in the ensemble conditions.

Bending Tasks: Standing Trunk Flexion and Kneel and Rise:

- Ensemble A's standing trunk flexion performance was statistically lower than that of the duty uniform alone for both test groups. This indicates that the Ensemble A's design limited the ability for the test subjects to bend at the waist and touch their toes.
- All ensembles allowed the test subjects to kneel and rise with no assistance.

Mission Scenario: Perimeter Control:

- There were no statistical differences in performance between CB ensembles and the duty uniform configurations for either test group. Each group generated large variances, which are likely the reason why there were no statistical differences, despite the magnitude of the difference in the measurements.

Mission Scenario: Tactical Operations:

- Ensembles A and C were statistically slower overall than the duty uniform alone for both groups.
- Ensemble A was statistically faster in completing Subtask 5, radioing to the team that the subject is exiting with the "assailant" in custody, than the duty uniform alone for the HRV group.
- Several subtasks were executed statistically slower by the Trooper group when wearing an ensemble than when wearing the duty uniform, as follows:
  - Subtask 1 was executed statistically slower in Ensembles A and C. This subtask included descending stairs, searching and clearing areas, walking, opening doors, and dealing with and arresting an armed suspect.
  - Subtask 3 was executed statistically slower in Ensembles B and C. It included holstering a weapon, handcuffing a suspect, and communicating with the suspect.
  - Subtask 7 was executed statistically slower in Ensemble A. This subtask included walking, clearing an area, and dragging a downed officer.
  - Subtask 8 was executed statistically slower in Ensemble A. This subtask included clearing a weapon, running, and scaling a wall.

Mission Scenario 3: Crime Scene Investigation:

- Ensemble B was statistically slower than the duty uniform for the HRV group.
- Ensemble B severely limited hand mobility and dexterity, according to subjects' accounts and evaluators' observations. This system used a two-part glove system in addition to the three to six pairs of latex gloves worn for evidence collection.

Combined HRV and Trooper Data for the Mission Scenarios:

- No statistically significant interaction effects were found for any of the scenarios.

6 Conclusions

This ergonomics evaluation utilized a unique approach towards evaluating human factors performance characteristics of CB protective ensembles. The use of generalized laboratory test methods for range of motion combined with LE specific mission-based scenarios allowed for a more representative and comprehensive analysis of LE user movements. The purpose of this evaluation was to provide test methods capable of evaluating LE representative CB ensemble ergonomics performance. It also served to set the baseline for ergonomics performance levels for LE CB protective ensembles.

Existing CB protection standards are limited in addressing the range of human factors considerations of interest to the LE community. The few standards which delve into systems level ergonomic performance are not aligned with LE's human factors evaluation needs, specifically as they relate to their mission roles, tasks, and movements when responding to a CB incident. Most of these existing standards utilize ASTM F 1154, *Standard Practices for Quantitatively Evaluating the Comfort, Fit, Function, and Integrity of Chemical-Protective Suit Ensembles*, to evaluate human factors considerations related to CB protective ensembles. However, ASTM F 1154 is limited in scope and applicability within the context of LE response to CB incidents. The tests outlined in ASTM F 1154 are global and general, allowing pass/fail testing only for general ensemble performance and do not allow for quantitative evaluation of ensembles or evaluation through mission-based tasks. In addition, Procedure "A" in ASTM F 1154 is geared towards suit/system integrity rather than overall suit performance and ability to complete duties, such as those required of tactical officers.

Wearing a CB protective ensemble has been proven to degrade overall performance; however, it is critical to ensure that the appropriate tests are conducted to measure the degradation in performance quantitatively based on LE mission related tasks. The test methods utilized in this assessment provide this detailed evaluation and allow for realistic and repeatable measures of LE performance decrement in CB protective ensembles.

These test protocols can be utilized as part of LE specific performance standards to ensure that the proper range of motion and human factors performance is achieved. Individual performance requirements should be established for each of the tasks and scenarios outlined in this report. As the ensembles performed differently depending on the type of movement required, a complete assessment of the ergonomic performance of the system will require the inclusion of each of these characteristics. In addition, this study highlights that LE professionals should be used during ergonomic certification testing. This will reduce the likelihood of integration effects seen when using an inexperienced data pool.

The development of improved standards which specifically address the needs of the LE community is necessary to ensure that the protection needs/requirements of LE personnel are being met while affording the ability to complete their overall missions. As LE operations have different requirements than other responding agencies under conditions of CB threats, the need for additional standards that are specifically designed to meet the needs of the LE community is essential. The recommendations identified in this report will be provided to NIST-OLES for consideration when developing LE specific CB standards. The results of this evaluation will be

used to recommend minimum human factors performance levels to NIST-OLES for consideration when developing LE specific performance standards for CB PPE ensembles.

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Acronyms

ACU	Army Combat Uniform
ACH	Advanced Combat Helmet
APR	Air Purifying Mask
BDU	Battle Dress Uniform
CB	Chemical/Biological
DHS	Department of Homeland Security
EOD	Explosive Ordnance Disposal
HLSO	Homeland Security Operations
HRV	Human Research Volunteer
JB2GU	JSLIST Block 2 Glove Upgrade
JSLIST	Joint Service Lightweight Integrated Suit Technology
LE	Law Enforcement
LEAP	Law Enforcement Advanced Protection
NBC	Nuclear, Biological, and Chemical
NFPA	National Fire Protection Association
NIJ	National Institute of Justice
NIOSH	National Institute for Occupational Safety and Health
NIST-OLES	National Institute of Standards and Technology - Office of Law Enforcement Standards
NPC	National Protection Center
NSRDEC	U.S. Army Natick Soldier Research, Development and Engineering Center
MOS	Military Occupational Specialty (US Army)
MSP	Massachusetts State Police
OSVT	Opposing Forces Surrogate Vehicle Training
PPE	Personal Protective Equipment
SCBA	Self Contained Breathing Apparatus
STOP	Special Tactical Operations
SD	Standard Deviation